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THE THEORY OF THE GAS ENGINE.

By DUGALD CLERK.

From Proceedings of the Institution of Civil Engineers.

II.

DISCUSSION.

Mr. D. CLERK mentioned that Dr. Siemens had worked out the method of compression used in engine type 2 in 1860 in so complete a manner that no advance had since been made on it by any one. Dr. Siemens was again working at this type of engine, which, from the fact of it using hot cylinder and regenerator, Mr. Clerk was certain was the best type for the very large gas engines to be developed in the future. With respect to the cold cylinder engine, of which alone he had treated in the paper, he wished again to insist on this: that the theory which sought to explain the so-called sustained pressure on the indicated diagram by the hypothesis of slow inflammation (erroneously termed slow combustion) was a false one. That when maximum pressure was attained in the gas engine cylinder it was certain that the whole mass was completely inflamed, and that no system of stratification producing slow inflammation could do good, but was quite opposed to the conditions of economy.

Dr. SIEMENS said that one part of the paper dealt with matters regarding the mechanical arrangement of gas engines, and the other with a theoretical question, that of the law of combustion. He would refer to the theoretical part first, because the author appeared to attach great importance to it, and as Dr. Siemens had from time to time given a great amount of consideration to the action of negative combustion or dissociation, it might be of some interest to the members to see how far his views fell in with those set forth by the author. It was well known that by combustion no unlimited degree of temperature could be attained. Thus, in a furnace worked at very high temperature the fuel was not completely burned when it came in contact with the oxygen of the heated or non heated air. The moment a certain comparatively high temperature was reached the carbon refused to take up oxygen, or the hydrogen refused to take oxygen, and what had been called by Bunsen, and, shortly after him, by St. Claire Deville, dissociation, arose. The point of dissociation was not a fixed one; partial dissociation came into play at a comparatively low temperature, and went on increasing at a higher temperature in very much the same ratio as vapor density increased with temperature. Thus, if aqueous vapor were passed through a tube at a sufficient

temperature the whole of the vapor would be dissociated, and the oxygen and the hydrogen would be separated. It was true, if these gases were left to themselves they would, the moment the temperature lowered again associate or burn; but if precautions were taken to cool them rapidly after they had attained that high temperature they would be found as a mixture of oxygen and hydrogen simply. The author had stated that the law which governed these actions was not well known and required research, but Dr. Siemens would like to know whether he was aware of the researches of St. Claire Deville on the subject. It might be that the determinations of St. Claire Deville were not quite correct, but in the meantime they might be regarded as being so. He found that at atmospheric pressure the point of half dissociation of aqueous vapor arose at a temperature of 2,800° Centigrade, and that of complete dissociation at a much higher temperature. Taking that law as determined by the French philosopher, it did seem reasonable to suppose that when a mixture of hydrogen and oxygen, with or without a mixture of nitrogen exploded, the point was reached beyond which the temperature did not increase, and, according to the author, that point was 1,500° Centigrade. If such a temperature was reached in a working cylinder complete combustion would not take place immediately, but only partial combustion would occur, which would go on as the temperature diminished by absorption into the cylinder or by expansion, and that combustion would be completed only in the course of the stroke. In that way the action which had been described with reference to the diagrams was reasonable enough. With regard to the mechanical arrangement of gas engines, the author distinguished between three types. In the first, the mixture of gas and air drawn in at atmospheric pressure was exploded. In the second, with which the author had connected his name as that of the first proposer, the combustion was produced gradually; the gases were ignited as they flowed into the heating cylinder. In the third type, the gases, after being compressed and mixed, were admitted into the working cylinder, and suddenly exploded. With reference to the early engine which Dr. Siemens constructed in 1860, the author had stated that it combined other elements, which were entirely wanting in the gas engines of the present day. The gas engine of the present day, taking either of the three types, was, in his opinion, in the condition of the steam engine at the time of Newcomen. The fuel was burnt in a cylinder which it was attempted to keep cold by passing water over it, and it was easy to conceive that the heat so generated, was only partly utilized for maintaining the state of expansion of the heated gases, the cold sides of the cylinder taking a good half of it away at once, thus causing a great loss. Then there was another palpable loss in these engines. After expansion had taken place, after half the heat had been wasted in heating a cylinder which was intended to be kept cool in order to allow the piston to move, the gases were discharged at a temperature of 1,000°, or in the best types about 700°. That amount of heat, representing in one case one-half and in the other two thirds of the total heat generated, was thrown away. This was heat which could be saved and made useful. Instead of commencing the combustion at a temperature of 60°, if the heat of the outgoing gases were transferred to the incoming gases, combustion might commence at a temperature of nearly 1,000°, and the result would be a very great economy. In the engine which he constructed in 1860 (Fig. 13) all those points were fully taken into account. The combustion of the gases took place in a cylinder without working a piston, and in a cylinder that could be maintained hot, and the gases after having completed expansive action, communicated their heat by means of a regenerator to the incoming gases before explosion took place. Although the engine was not worked with ordinary gas used for illumination, but by a cheaper kind made in a gas producer, he then thought that a gas engine constructed on that principle would prove to be the nearest approach to the theoretical limits which could never be exceeded, but which might exceed the limits of the steam engine four or five fold. The engine promised to give very good results, but about the same time he began to give his attention to the production of intense heat in furnaces, and having to make his choice between the two subjects, he se-

lected the furnace and the metallurgic process leading out of it; and that was why the engine had remained where it was for so long a time. But now the time had come when there was a greater

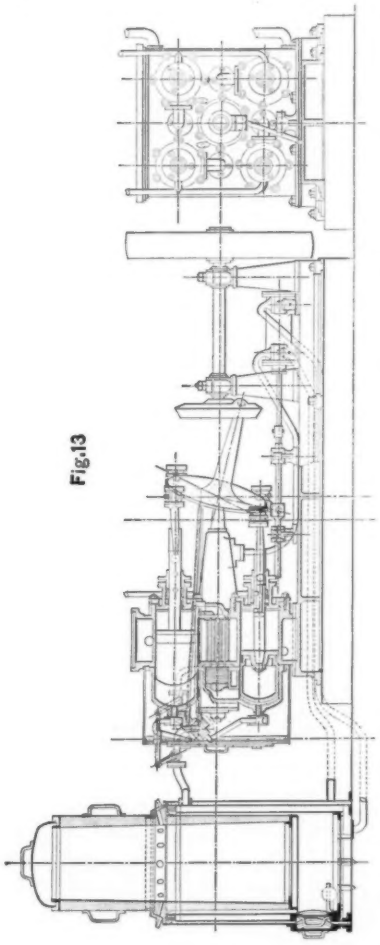


Fig.13

demand for engines of a smaller kind to do their best in houses and in small works, and when marine engineers especially had become fully alive to the importance of more economical arrangements. He therefore looked upon the question before the Institution as one of first importance to engineers, and he hoped that it would be well discussed.

Professor RUCKER said that in his work on Thermodynamics, Mr. Verdet had published a calculation of the theoretical efficiency of an ideal gas engine. He assumed that no heat was lost through the sides of the cylinder, and that the explosion was so sudden that the whole of the gas was inflamed before the piston had appreciably moved; and under those circumstances he found that if the gases used were carbonic oxide, and a sufficient quantity of air to burn it completely, and if the whole of the carbonic oxide was burnt, the temperature to which the gases would rise, on the assumption that their specific heats remained constant, was 4.388° Centigrade. He found that the pressure would rise from 15 lbs. per square inch to 215 lbs., and that the efficiency of the engine would be 41 per cent.—that was, that 41 per cent of the total amount of heat produced by combustion of the gas would be converted into useful work. It was evident from the conditions of Mr. Verdet's problem that that was a purely theoretical calculation. The condition, for instance, that no heat was lost was one which could not be realized in practice. About four years ago, however, in the course of a series of lectures given by some of his colleagues and himself on coal, he pointed out that Mr. Verdet's calculation was not even theoretically correct; that Bunsen had proved that it was impossible that a mixture of carbonic oxide and air could reach such a temperature as 4,388° Centigrade, which was something like 2,800° above the highest temperature, which Berthelot had shown was consistent with Bunsen's experiments on the subject. The question then arose what the effect of dissociation would be upon the gas engine, and Professor Rucker attempted to make a rough calculation to show how important it might be. In the first place, he assumed that the highest temperature which could be reached was that given by Bunsen's experiments, and in the next that the specific heats were constant and the inflammation instantaneous. With those conditions only about one-half of the carbonic oxide would be burned when the highest temperature was reached; then, as the piston began to move forward and the temperature fell, more would be consumed. But then there was the very important question

as to how the temperature would fall, and in order to calculate that the law of cooling of a body heated to that extremely elevated point must be known. That, of course, he was ignorant of, and he was therefore obliged to make a rough assumption. Assuming that, as the piston moved forward, the gas burned so as to keep the temperature constant, he found that at the end of the stroke, when the pressure had fallen to that of the atmosphere, a part of the gas was left still unconsumed. Therefore in the half of the gas left unburned to begin with, there was sufficient to do all work that was done while the piston was moving forward. The only assumption he could make was that the temperature remained constant; any other, though that certainly was not true, would have involved some still more arbitrary hypothesis as to the law of cooling. Making, then, that rough assumption, he found that instead of a temperature of 4,000° Centigrade the highest reached would be about 2,000°; that the pressure, instead of rising to 215 lbs., would rise only to 103 lbs.; and that the efficiency of the engine would be only 25 instead of 41 per cent. That, though a very rough calculation, showed at once what the enormous importance of the phenomenon of dissociation might be. It served the purpose for which it was put forward, and showed that in any theory of the gas engine physicists must make up their minds as to what part dissociation played in it. Passing from the theoretical problem to that Mr. Verdet and himself discussed, namely, the case in which there was only enough air to burn the carbonic oxide completely, to the practical problem in which there was a much larger quantity of air present, a case arose in which dissociation was less important. The larger the quantity of air present the lower the highest temperature would be, and therefore, probably, the smaller the amount of dissociation. St. Claire Deville had shown that carbonic acid was dissociated at temperatures between 1,000° and 1,200°, and water at temperatures between 1,000° and 1,100° Centigrade. Inasmuch, therefore, as in the author's engines, the highest temperature reached was about 1,500° (or 400° or 500° above the limits put by St. Claire Deville), it followed that if his measurement of the temperature was correct, which there was every reason to believe it was, and if St. Claire Deville's experiments were trustworthy, there was a certain amount of dissociation at the temperatures reached in his gas engine. Passing, however, to the next question, namely, how much dissociation there was, the problem was much more difficult. With regard to that subject a series of papers had recently appeared in the "Comptes Rendus de l'Académie des Science," which were so much to the point that he might be excused for giving a short account of one or two of the leading results at which the experimenters had arrived. The two gentlemen in question were Mr. Mallard (whose experiments on the rate of propagation of inflammation in gas had been mentioned by the author) and a colleague, Mr. Le Chatelier. They had been making a number of experiments such as those that the author had advocated in his paper. They had made, indeed, what appeared to be one of the first serious attempts to investigate what was going on in gas heated between 1,000° and 1,500° Centigrade. The plan they adopted was as follows: They exploded gases in an iron cylinder, attached to which was a Bourdon manometer; to that was attached a needle, which registered the pressure on a revolving cylinder. By reading off the curve so obtained, they got information as to the pressure in the cylinder at different times. He could not altogether accept their results without further confirmation. Some of the conclusions at which they had arrived were so striking that he thought they must certainly be supplemented by other experiments before they could be accepted. But for the moment he would put aside all difficulties connected with the experiments, and simply state the conclusions. It was found, dealing with gases at very different temperatures, that the curves obtained upon the revolving cylinder showed a point of discontinuity. At the very highest temperatures the curves were somewhat different from what they were at low temperatures, and the assumption they made was that at the high temperatures dissociation had set in, whereas at the lower temperatures

there was no dissociation; therefore the law of cooling would be different in the two cases. If, however, that interpretation of the experiments was accepted, it would be found that the temperatures at which dissociation took place to any considerable extent were higher than those he had mentioned. Thus the authors stated that carbonic acid did not dissociate appreciably below 1,800° Centigrade, and that steam-gas did not dissociate appreciably below 2,000°. Here, then, there were temperatures considerably above those obtained in the gas engine; if, therefore, the results in question were to be accepted, dissociation could not play a very important part in the matter. But although at first sight the experiments told against dissociation taking place to any large extent, in order to account for the phenomena they observed, Messrs. Mallard and Le Chatelier had had to introduce another hypothesis which practically came to very much the same thing. In all the earlier calculations upon the subject the assumption had been made that the specific heats of the gases were the same at high as at very low temperatures, but within the last few years two or three experimentalists of note had brought forward results tending to show that the specific heat of the gases increased as the temperature rose. The two most important researches made upon the subject were those by Professor E. Wiedemann and Professor Wüllner, the latter of whom showed that at temperatures between zero and 100° Centigrade there was an appreciable rise in the specific heat of gases at a constant volume. Messrs. Mallard and Le Chatelier had taken that hint, and they found that in order to explain the facts observed by them on the assumption that there was no dissociation, they must assume an enormous increase in the specific heats of the gases at high temperatures. But there were one or two points which appeared to present difficulties in their way. Wüllner showed that at the temperatures at which he worked, as might be *prima facie* expected, the increase was much greater in a compound gas like water or carbonic acid than in an elementary gas such as oxygen or nitrogen. But Messrs. Mallard and Le Chatelier completely reversed that, and found that the increase was much greater in the elementary gases than in the compound ones; and they went so far as to show that oxygen would at a temperature of 1,000° have a specific heat no less than one hundred and sixty-five times greater than that which it had at zero. That result was so astonishing that it could not be accepted without much more proof than had at present been offered. But putting aside for the moment Messrs. Mallard and Le Chatelier's interpretation of the experiments, he wished to consider what they meant from a wider point of view, viz, that those gentlemen had come across a phenomenon which pointed to the fact that a vast quantity of heat was rendered latent. If specific heat at constant volume increased, the meaning of it must be that the work done by the heat was done within the molecules of the gas, that the heat was spent in separating or preparing for separation the atoms of those molecules, which were gradually being forced asunder; whether they were actually forced asunder or not might be a question, but a large amount of work was spent in separating them, or preparing to separate them, by loosening the bonds between them; and Messrs. Mallard and Le Chatelier's experiments served as much as anything previously brought forward to illustrate that point. He thought it must be assumed with almost certainty that a large quantity of heat was rendered latent in gases at temperatures between 1,000° and 1,500° Centigrade. All would agree that a certain amount of that heat was spent in dissociation (for Messrs. Mallard and Le Chatelier stated that they harmonized their results with those of St. Claire Deville by supposing that his experiments were more sensitive than their own), and the remainder of the heat would be spent, if not actually in dissociation, in preparing for dissociation. There was one other point in the paper which he thought of interest. The author had pointed out how different the rate of propagation of an explosion would be in the case of gaseous mixture which was confined to that in an unenclosed space. Messrs. Mallard and Le Chatelier had made experiments on that point; they had inflamed gas and air mixture in a tube closed at one end, and they found that when it was inflamed at the closed

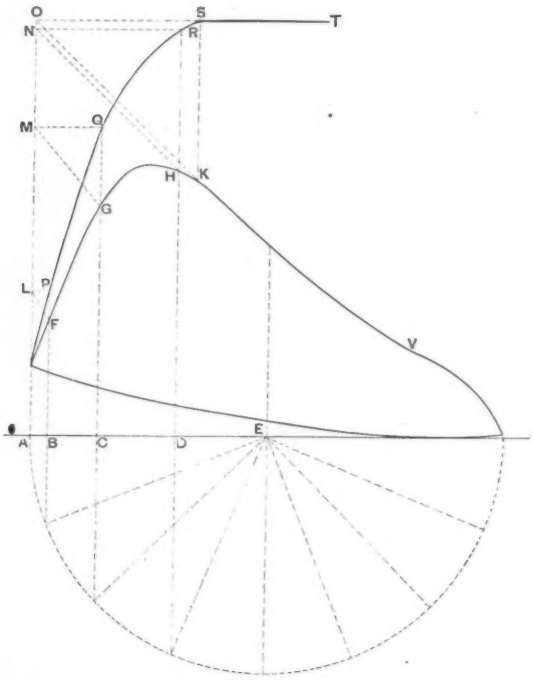
end the rate of propagation was much greater than when it was inflamed at the open end. In the one case the gas was merely burning backwards through the tube, in the other the expansion of the gases would spread the inflammation. So enormous was the difference, that in some cases they found that the rate of propagation was one hundred times greater when the gas was lighted at the closed end of the tube than when it was lighted at the open end. That was a point which strongly confirmed the author's view—that inflammation spread through the gas almost instantaneously. Although, therefore, one could not but feel that on those points there was a great lack of experimental data, all the facts that were brought together, might, at present, be best explained by the hypothesis that the inflammation spread very rapidly through the gas, and that at high temperatures, say of over 1,000°, a very large amount of heat was rendered latent, either in actual dissociation or in incipient dissociation. Here, then, was an explanation of the curious maintaining of the temperature to which the author had referred. As the gas cooled, the latent heat was given up and the curve was thus kept up to a high temperature by the heat previously absorbed in the molecules of the gas.

Mr. W. R. Bousfield did not propose to quarrel with the greater part of the facts stated, which were for the most part indisputable, but he thought neither the interpretation which the author had put upon them could be upheld, nor the new and, to most of them, rather startling theory of the action of the gas engine which had been submitted in the paper. He did not say that the phenomena of dissociation played no part in the action of the gas engine; he did not say that when the explosion took place, there might not be a certain quantity of ammonia and a certain quantity of nitric acid formed, and that the phenomena of dissociation might not take place to a certain extent; but what he did say was that neither the formation of nitric acid nor the formation of ammonia nor any of the phenomena connected with dissociation could account for the facts mentioned. He would only refer to two of those facts, namely, that notwithstanding the enormous loss of heat through the walls of the cylinder of a gas engine, amounting to 50 per cent. of the total amount of heat put into the cylinder, the curve of the indicator diagram still kept up the theoretical adiabatic line which it should follow, supposing the whole of the gas were burned at the beginning of the stroke, and the walls of the cylinder were non-conducting. That was a startling fact which had to be dealt with in one way or another, but the interpretation of the fact seemed to him to be very simple, and even in the paper there were materials for arriving at a conclusion upon it. The author had stated that a mixture of gas and air took a certain time to ignite, that if ignition was set up at one point it took a certain time before it was communicated to another. There was also the further fact that at the rate of communication of the ignition from one point of the dilute mixture to another varied directly with the amount of dilution of the mixture. Supposing for instance there was a mixture of gas and air in the right proportions for explosion, the ignition would take place at a certain speed; if more air was put in, the rate would be less; the greater the quantity, the less the rate at which the ignition traveled. That simple fact he thought sufficient to account for all the phenomena. The diagram which the author had given (Fig. 9) seemed to him, taken in conjunction with the fact to which he had referred, to support the theory which had been put forward by Mr. Otto and by the scientific world in general. In the Otto gas engine the charge varied from a charge which was an explosive mixture at the point of ignition to a charge which was merely an inert fluid near the piston. When ignition took place, there was an explosion close to the point of ignition that was gradually communicated throughout the mass of the cylinder. As the ignition got further away from the primary point of ignition the rate of transmission became slower, and if the engine were not worked too fast the ignition should gradually catch up the piston during its travel, all the combustible gas being thus consumed. When the engine was worked properly the rate of ignition and the speed of the engine ought to be so timed that the whole of the gaseous contents of the cylinder should have been burned

out and have done their work some little time before the exhaust took place, so that their full effect could be seen in the working of the engine. This was the theory of the Otto engine. What was the theory which the author had put forward? He had stated that when gases combined a high temperature was set up; that a high temperature prevented combination of the gases beyond a certain point; and therefore, at the moment of ignition, there existed in the cylinder a body of gases heated to a temperature beyond the point of dissociation. A part of those gases being in a state of combination, and having therefore given out a heat which was doing the work of pushing the piston; a part of the gases, not being in a state of combination, being ready to combine as soon as the temperature was lowered to such a point that they could combine and give out work. Looking at that theory, it seemed as if the point involved was a mere question of words, so far as regarded any question of infringement. In either case, what had to be dealt with was this. The adiabatic line represented the line which was traced out upon the indicator diagram when no heat escaped through the walls of the cylinder, and when the whole heat which the gases lost was converted into work done by the piston; so that, taking an indicator diagram, and finding the work done as represented by the area included by the curve, the ordinates and the atmospheric line, this work ought to be equal to the quantity of heat, represented in foot-lbs., which had been given out by the gas, as shown by the difference of temperatures and specific heat of the gas. Of course, when heat was escaping through the cylinder, and when the adiabatic line was still kept up to, a considerable amount of energy must be developed somewhere, in order to make up for the energy which went through the walls of the cylinder. The only source of energy in the gas engine was the union of combustible gases and oxygen, and it followed that that constant supply of energy must come from the combustion of the gases within the cylinder. It was therefore a mere question of words, because, whether the energy was developed by the combustion of the gases which took place through the lowering of the temperature below the point of dissociation, or whether that energy was given out through the combustion of the gases which took place from the communication through the mass of an ignition which traveled slowly through it, in either case it was a gradual combustion. It was therefore a mere question of theory, and he did not see in what way it could affect the question of infringement. If Messrs. Crossley and Mr. Otto had overlooked the theory of dissociation, and had attributed the gradual combustion to something which they ought not to have attributed it to, he did not see how it could affect their position. The real point of difference, however, in a scientific point of view, between the author and himself was this. The author assumed that the ignition was quickly transmitted through the cylinder, and took place almost at once near the beginning of the stroke, and that the ultimate combustion was due to dissociation; whereas Mr. Bousfield thought with Mr. Otto and many others that the cause of the supply of energy was the gradual communication of ignition through the contents of the cylinder. The author assumed gratuitously that when the point of maximum pressure was reached, that point marked the communication of ignition throughout the whole of the cylinder. That there was absolutely no ground for that assumption could be very readily shown. Neglecting for the moment the loss of heat through the walls of the cylinder, the curve representing the increase of pressure due to the combustion of the gas, supposing the gases to combine at the same rate as they actually did, but not to be allowed to expand by the motion of the piston, could be ascertained thus:—Divide the atmospheric line (Fig. 14) into spaces AB, BC, CD, DE, &c., representing equal small spaces of time, or equal parts of a revolution. From each of the points A, B, C, &c., raise ordinates AL, BF, CG, &c., to meet the indicator curve in the points F, G, H, &c., and from the points F, G, H, &c., draw adiabatics to meet AL in L, M, N, &c. From L, M, N, &c., draw lines parallel to AB to meet their corresponding ordinates in P, Q, R, &c. Then the curve P, Q, R, &c., drawn through these points, would be a curve, the ordinates

of which were proportional to the pressure at any time of the contents of the cylinder, supposing these contents to remain confined in the space at the end of the cylinder, and not allowed to expand, and supposing the rate of combustion of these contents to be exactly the same as actually occurred. This curve, therefore, showed the actual progress of the combustion deduced from the stroke. Hence the maximum point on the diagram was simply the point where the increase of pressure due to combustion was balanced by the decrease of pressure due to the forward motion of the piston, and there was no reason for saying that this maximum point corresponded to complete ignition. He had had an opportunity of taking diagrams from the Otto gas engine, which Pro-

Fig.14.

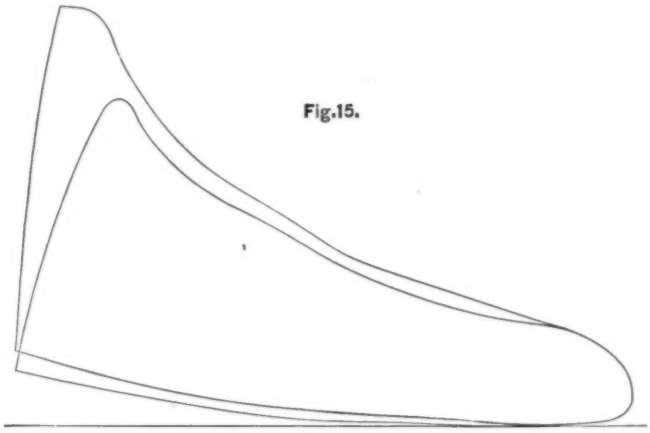


the working diagram. Even neglecting the loss of heat through the walls of the cylinder, it would be seen that this curve ascended to a point past the point of maximum pressure, viz., till the point K, at the commencement of the part KV (which was supposed to be exactly adiabatic) was reached. From the point S this curve became in the actual diagram a straight line parallel to AB. If, however. the theoretical diagram, allowing for loss by conduction, were taken, the curve PQRS would ascend throughout

fessor Ayrton had at the City Guilds Technical School, Cowper Street. The engine was designed for the electric light, and the cam, controlled by the governor, was made in a series of steps. He therefore had the governor taken off, and the cam and the roller on which it acted so arranged that it should work independently of the velocity of the engine on a given step, so that the charge might be, as nearly as possible, the same at all speeds. And he varied the load by braking the fly-wheel. The

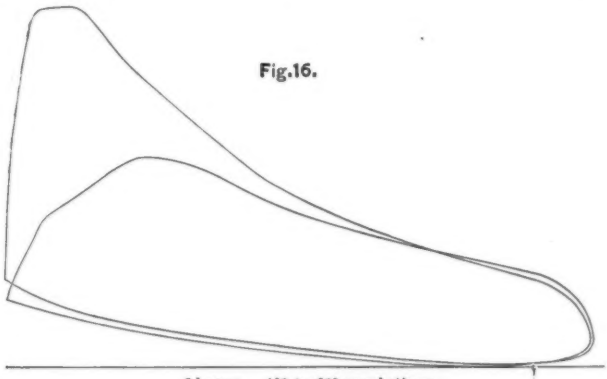
two sets of diagrams were taken, one at a speed of one hundred revolutions, and the other at two hundred; thus might be seen the effect which must be due to the phenomenon he had spoken of—the ignition traveling gradually; it could not be due to dissociation, for the reason which Mr. Imray had pointed out. In the diagrams the phenomena of dissociation ought to be exaggerated at the higher temperature, but instead of that, it would be seen that the effects attributed to dissociation were less at the higher temperature where dissociation should be most active, and greatest at temperature below the point of dissociation; he therefore did not see why the results should be attributed to the phenomena of dissociation, when they could be perfectly explained by the rate of progress of ignition through the cylinder. With the full charge at one hundred and at two hundred revolutions the effect of difference of speed was small, as shown by the two diagrams in Fig. 15. In that case, the rate at which the ignition went through the cylinder was so great that it only made a very little difference in the curve when the rate got up to two hundred revolutions. He then fixed the roller on the third step, when there was a less charge of gas. The diagram, Fig. 16, showed the hundred-revolution curve, in which the gas had time to explode, and to carry the pencil indicator up to the maximum point, and

Fig.15.



4th step. 100 to 200 revolutions.

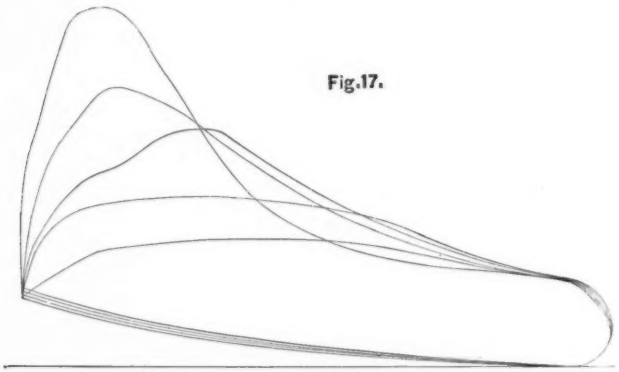
Fig.16.



3d step. 100 to 200 revolutions.

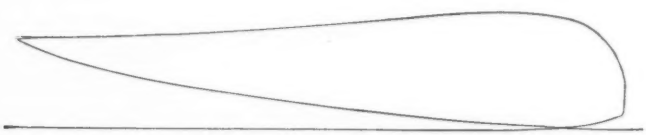
then down to the adiabetic line. Going to two hundred revolutions with the more dilute mixture, the rate of propagation of ignition was slower; therefore at that speed, although the temperature was less, dissociation would have much more to do. The effect was much more marked, simply from the dilution of the mixture; there was therefore a less rate of propagation of ignition, and the curve took the form shown in the diagram. Fig. 17 showed the same effects on the diagram when the curve roller was on the second step, and consequently still less gas was admitted. The five superposed diagrams were taken at speeds between one hundred and two hundred revolutions per minute. It would be observed that the curve at the higher speed generally went outside the door There was less work done at the beginning, and more gas to be combined at the end, and therefore a greater amount of work done at the end of the stroke. He did not wish to carry the comparison all the way through, but he would leave it to the author to show how he explained the diagrams under the dissociation theory. In Fig. 18 there was the least amount of gas with which the engine would work, and the speed was one hundred and thirty revoluions. The compression was 30 lbs.; the compression line was the same as the others. The working line was a line nearly parallel with the atmospheric line, but slightly rising, and at the end the ignition was not finished, indeed, in this case, if a light was applied to the exhaust the contents would explode. According to the author's theory, that maximum point near the end of the stroke in the last diagram was a point where the ignition was complete, and therefore all the gas should have combined at that low temperature where no dissociation could take place. Those were points which the author would have to meet in order to support his theory. Many of the facts mentioned by the author were incontestable, and his chief dispute with him was as to the interpre-

Fig.17.



2d step. 100 to 200 revolutions.

Fig.18.



1st step. 130 revolutions.

tation he had put upon them. The author had said nothing against the theory to which he had referred except that it was new, no argument whatever being advanced against it. The author stated, "From the considerations advanced in the course of this paper, it will be seen that the cause of the comparative efficiency of the modern type of gas engines over the old Lenoir and Hugon is to be summed up in one word, 'compression.'" He had not had time to go carefully through the diagrams; but he did not think that they were fair comparisons, and he thought that other elements ought to have been taken into account. The author had given the old Lenoir, and had stated that the temperature was the same, that the mixture of gas was the same, and that the great advantage over the Lenoir was compression. Mr. Bousfield might be permitted to point out that, in the Lenoir engine, the adiabatic line was much above the actual line. It would be fairer to substitute the word "dilution" for "compression," so that the sentence would read: "The cause of the comparative efficiency of the modern type of gas engines over the old Lenoir and Hugon is to be summed in one word, 'dilution.'" The fact, however, was that it could not be summed up in one word; the two should be taken together, compression and dilution. The author further stated: "The proportion of gas to air is the same in the modern gas engine as was formerly used in the Lenoir." He did not think so. He believed that the Lenoir worked up to 13 to 1, and could not get further. He did not know what proportion Otto used, but it was considerably more than that. It was also stated that the time taken to ignite the mixture was the same; but that was a gratuitous assumption. The author said: "The cause of the sustained pressure shown by the diagrams is not slow inflammation (or slow combustion as it has been called), but the dissociation of the products of combustion, and their gradual combination as the temperature falls, and combination becomes possible. This takes place in any gas engine, whether using a dilute mixture or not, whether using pressure before ignition or not, and indeed it takes place to a greater extent in a strong explosive mixture than in a weak one." Dissociation took place far more at high temperatures than at low; and if the author's application of the theory were correct the phenomena of dissociation ought to play a much greater part at high than at low temperatures. He had pointed out that this was not so in the diagrams, and that it was not so with Lenoir's explosive engines where the curve fell far below the adiabatic line. The paper contained other matters which he had not time to dwell upon; but he thought he had said enough to challenge the author to show how he got rid of the old theory, and explained the facts to which Mr. Bousfield had referred.

Dr. JOHN HOPKINSON said a very interesting question had been discussed by Professor Rücker and Mr. Bousfield, to which he desired to refer. The author maintained that the ignition of the mixture of gases had extended throughout the whole space at a time approximately represented by the point of maximum pressure. Others, on the contrary, maintained that the ignition had not extended through that space by that time, but that it took a time lasting into the descending part of the indicator diagram before the disturbance had extended throughout the whole of that space. The author attributed the maintenance of the temperature during the latter part of the curve, and its approximation to an adiabatic curve, to the gradual combination of the gas through the mass, that combination not occurring completely in the first instance owing to the temperature being so high that a certain measure of dissociation occurred, or at all events so high that comptete combination could not occur. He thought that the question might be submitted to a crucial test. Suppose the opponents of the author were right, if a given mixture of air and gases were exploded in a gas engine revolving at a low rate of speed or in an entirely closed space, it would be expected that the maximum pressure would approximate to that calculated from the heat due to the combustion of the gas present and the temperature resulting therefrom. If the gine were running slowly, or if the explosion were made in a completely confined space, the pressure would be expected to rise to a point very greatly in excess of that observed in the gas

engine running at its normal speed. Whether that were so he did not know. The experiment might be objected to on the ground that when the engine was running slowly there was a great loss of heat through the walls of the cylinder. That would give rise to a second crucial experiment. If the author was right the maximum pressure in large and small engines would be about the same; if those who differed from him were right, in a large engine the maximum pressure would probably be greatly in excess of that in a small engine, there being less loss of heat through the walls of the cylinder. What the answer might be he did not know, but it appeared to him that there were there the elements of settling the question. The author divided gas engines into three classes, and had made a comparison of their theoretical efficiency. In the second the mixtures were admitted into the cylinder, and, without increase of pressure, the heat produced was devoted to increase of volume. In the third the mixtures were introduced into the cylinder, and then burned with an increase of pressure without immediate increase of volume; and in those two cases he took, for the purpose of comparison, different maximum pressures. In the second type he took a pressure of 76 lbs., and in the third over 200 lbs. *Prima facie* it would seem natural, in order to make a fair comparison, that the same maximum pressure should be taken in the two cases. Probably the author had a good reason to justify his making a comparison on that basis, and, perhaps, in his reply he would point it out. He agreed with those who had so often spoken on the subject of the gas engine that in that engine lay the future of the production of power from heat of combustion. It was quite in its infancy, and it had already beaten the best steam engines in economy of fuel, for the obvious reason that it was practicable to use with it much higher temperatures. The steam engine tolerably approximated to the theoretical efficiency that might be expected from it, having regard to the temperatures between which it was practicable to work it. That was not the case with the gas engine, there being still a very large margin for practical improvement. Having regard to the very short time during which gas engines had been used, he thought that practical improvements would take place, and that, when such difficulties as that of starting a large engine as conveniently as steam engines could be started had been overcome, the gas engine would supersede the steam engine.

Mr. E. F. Bamber wished the author had commenced his paper with that portion which treated of the analysis of the gas, and had given the mechanical equivalent of a unit of the same both in the pure and diluted state. If the explanation had then followed, that the mechanical equivalent of the latent heat of expansion per unit of the gaseous mixture per degree of temperature was nearly the same as for atmospheric air, the reason why the gas engine might be considered in theory as an air engine would have been clearer, namely, that the adiabatic curve, or curve of no transmission of heat, was nearly the same for both. The author commenced by an attack upon the steam engine. Much heat was required in evaporating water whose specific heat was high, and hence the efficiency of the steam engine was low, and something better was needed; whereas it was clearly proved by Rankine, a quarter of a century ago, that the maximum efficiency of a theoretically perfect heat engine, working between given limits of temperature, was equal to the ratio of the range of temperature to the higher absolute limit of temperature, and quite independent of the fluid employed. Raising the temperature entirely by compression or using regenerators were the two means by which the actual efficiency might be made to approach the maximum limit. The author believed in compression, but his method of defence of it and his illustrations of its advantages did not appear to be quite correct. He took three types of engine: the first and third were explosive gas engines; the second was worked at constant pressure, and these he treated as air engines. The first and second were worked between the same limits of temperature, but in the second compression was employed. What the author wished to prove by the theoretical diagrams of these types was that the constant-pressure engine using compression was more theoretically perfect than an explosive engine using none, whilst an explosive engine using compres-

sion was the best of the three. But he had shown by type No. 2, that by the use of compression an efficiency could be attained higher than the maximum efficiency of a perfect heat engine, which seemed to require some explanation. The maximum was equal to $\frac{T_1 - T_2}{T_1}$ in absolute degrees of temperature, and was for 1,537° Centigrade and 1,089° Centigrade equal to 0.247 for both types; whereas the author made it 0.21 for the first and 0.36 for the second. The author allowed that type No. 1 would be improved by further expansion, but that that would require a vacuum pump and condenser; yet surely it made no difference, so long as they both consumed the same quantity of heat, whether a compression pump was used at the beginning or a vacuum pump at the end of the stroke, whilst indeed there might be theoretical reasons in favor of the latter. Types 1 and 3 were respectively worked without and with compression; they were both explosive engines, and the efficiency of the latter was made double that of the former, but the latter was made to discharge at 648° Centigrade, and the former at 1,089° Centigrade. If these figures had been reversed, so would have been the efficiencies. Had the author explained that there was a certain maximum efficiency for heat engines, and that by means of compression a larger percentage of that maximum could be attained than without it, there would have been no reason for objection; but that was a very different thing from trying to show that it was possible to obtain more than the maximum efficiency of a theoretically perfect heat engine.

The real value of the gas engine was, that it contained the furnace and engine in one; thus the necessary heat lost in the furnace to make a draught, and the unnecessary loss of heat by radiation from a large steam boiler were both avoided in the gas engine, and, finally, the gas engine could be used safely at a maximum limit of temperature, which could not be employed in the steam engine. There was no doubt a great future for this class of motor.

Sir WILLIAM THOMSON said that he had recently seen a very interesting experiment made by the author with a gas engine at Glasgow, which he thought had a most important bearing on the mode of action of the gas in the cylinder. The experiment was made in the presence of his brother Professor James Thomson and Professors Jack and Ferguson (of Mathematics and Chemistry in the University of Glasgow), who were all much interested in the inquiry. The object was to test the nature of the mixture in close proximity to the piston, so as to be able to form some idea as to whether or not the explosion took place through the whole space; to be judged by finding whether, right up to contact with the piston, gas and air were present in proportions suitable for combustion. He need not enter into details as to the way in which the experiment was made, but he might say, in a general way, that while the piston was being pressed in to condense the mixture at a definite point of the stroke, communication was made with the cylinder. The small experimental cylinder and piston were placed in proper position, in communication with an aperture bored for the purpose in the main cylinder. The author of the paper would be able to explain the details better than Sir William Thomson could. It was sufficient to say that by an automatic arrangement, worked mechanically from the cross-head, the communication was made exactly at one definite point of the stroke, and the experimental piston was pressed up in the cylinder so as to let it fill. At any time afterwards the stop-cock could be opened by hand, and the nature of the contents tested. In every case the contents were found to be explosive—an explosive mixture of gas and air—proving that up to the very point, which he understood was within about an inch from the piston, coal gas was present in suitable proportions for producing an explosion. There was one other matter to which he wished to refer, which had been noticed in the discussion. There appeared to be some difference of opinion upon it, but to his mind it scarcely appeared open to doubt—that the diagram, which showed an exceedingly sudden rise and a gradual fall, proved that combustion was practically complete at a point corresponding to the summit of the curve. Literally and precisely the instant of the maximum of the curve was that at which the rate of loss of pressure by

expansion, the much smaller rate of loss of pressure by loss of heat carried by convection of the fluid to the solid boundary and out by conduction through the metal, were exactly counterbalanced by the rate of combustion still going on. It seemed certain that the rate of loss by the two causes he had indicated was exceedingly small in comparison with the rate of rise by the initial progress of the explosion; therefore, practically speaking, the maximum of the curve indicated truly the instant when the combustion was as complete as dissociation at the highest tempearature attained allowed it to be.

Mr. D. CLERK, in reply upon the discussion, said that two of the speakers seemed to think that the question at issue was one of infringement of patent, but he desired to arrive at the truth, apart from mere questions of personal interest. The question of infringement was to him one of complete indifference.

The question he was anxious about was the purely scientific one. Was his theory of the action of the gas engine the true one, or was it Mr. Otto's? This matter might appear to some persons a small one, but he considered it of vital interest, being convinced that not many years hence the gas engine would have a science of its own, and scientific names connected with it as much honored as any ever linked with the steam engine. Dr. Siemens had fully corroborated his view of dissociation, and in the effect it had on the gas engine diagram, in preventing the more rapid fall, which must otherwise occur; but he did not agree with him in the necessity for further research on dissociation, believing that St. Claire Deville's work was sufficient. Dr. Siemens would observe that St. Claire Deville's researches were referred to in the paper; but what he asked for had never to his knowledge been published, that was a complete curve of the dissociation of water and carbonic acid. St. Claire Deville's results were more of a qualitative than of a quantitative nature. He feared that the method used was not capable of the necessary accuracy.

He thoroughly believed that the engine for the very large powers to be constructed in future must be of one type 2, with hot chamber or cylinder, and regenerative contrivance in some form; indeed, about two years ago he constructed and experimented with such an engine, and he was continuing his experiments.

The mechanical difficulties were much greater than in the cold cylinder, type 3. It must be remembered that the cold cylinder gas engine was the engine of the present, and it was most satisfactory that even with the small sizes so high a duty should be obtained. It proved that when larger engines were made a much higher duty might be expected. The theory of the cold cylinder engine did not allow of the application of any regenerative contrivance, and consequently arrangements must be made to get the greatest possible fall of temperature due to work done. A very interesting account had been given by Professor Rücker of his view of the problem, and the necessity of correcting the calculations of previous observers in the light of present knowledge of the laws of combustion had been demonstrated. It was satisfactory that Professor Rücker so thoroughly agreed with him on the necessity for considering dissociation in any theory of the gas engine, and had independently arrived at similar conclusions. The experiments of Messrs. Mallard and Le Chatelier corroborated those of Professor Bunsen in this, that at the high temperature of combustion, a large amount of heat was rendered latent. So striking a fact could hardly have escaped the notice of many other experimenters who might not have published their results. He had noticed it about five years ago, while making experiments on the maximum pressure obtainable from a pure explosive mixture of gas and air. A cylinder 9 inches in diameter and 9 inches long, was filled with a mixture of gas and air in the proportions for maximum explosive effect, and ignited the mixture by means of a hollow stop cock, after Barnett's style of igniting arrangement. With the temperature of the mixture before ignition at 12° Centigrade, the highest pressure attained was 97 lbs. per square inch above the atmosphere. The pressure was measured by a loaded valve of known area, as in Bunsen's experiments. The absolute pressure attained was only about 7½ atmospheres; if complete combination had taken place, and no heat kept back by dissociation or absorbed by change in specific heat, then the pressure should have been at the lowest estimate, 11 atmospheres. He con

cluded that Professor Bunsen's explanation of this fact was a true one. The effect was equally visible in the large cylinder used by him and in the small tube used by Professor Bunsen. These experiments, and the recent experiments of Messrs. Mallard and Le Chatelier, make it certain that in a uniformly ignited gaseous mixture the temperature was limited, and the apparent loss of heat was very slow, and that this effect was due to dissociation, either complete or incipient. Such a mixture in expanding during work would give rise to all the phenomena described in the paper. He was pleased that his conclusions on the relation between rate of inflammation at constant pressure and constant volume had been experimentally proved by these gentlemen. He had been challenged by Mr. Imray to controvert his statement on the history of the introduction of the gas engine. This he did not do, because he considered Mr. Imray's account fairly correct.

The only remark of Mr. Imray on his theory was: "He would only refer to Fig. 9. If the theory of dissociation were true, it would follow that the lower the temperature the more dissociation would take place, which was undoubtedly altogether wrong." It was difficult to understand this statement, it was so exceedingly irrelevant. He could hardly believe the speaker had ever studied the pressure, volume, and temperature relations of gases. On the indicated diagram low pressure had been mistaken for low temperature, neglecting the increased volume due to the travel of the piston. Mr. Imray had supposed that the maximum pressure on line *d* (Fig. 9), being lower than on line *a*, therefore the temperature was also lower. He failed to see the bearing on the theory under discussion of Mr. Bousfield's statement: "He did not say that when the explosion took place, there might not be a certain quantity of ammonia and a certain quantity of nitric acid formed." The question why, when maximum pressure was reached at the beginning of the stroke, he assumed that the flame had spread throughout the mass in the cylinder was much more to the point. From the original of the diagram, Fig. 6, he had taken the two extreme lines shown at diagram Fig. 19, *a* and *b* were the points of maximum pressure. In the paper he had not detailed the method used to calculate the temperature attained at the point of maximum pressure; it was necessary to do so before proceeding further. First, he determined the exact volume of the space at the end of the cylinder into which the mixture was compressed, then on the diagram he had drawn the adiabatic line of compression, it was the dotted line shown at Fig. 6; the lower black line was the actual compression line drawn by the indicator. It would be seen that the two were as nearly as possible coincident. The cause of this had been pointed out. The temperature at the point *c* was known to be 150°.5 Centigrade, and the pressure 41 lbs. above atmosphere, and assuming the volume to remain constant, the temperature at *a* was calculated from the pressure 220 lbs. above atmosphere.

Let P = pressure before ignition, and P′ pressure after ignition, T = temperature before ignition and T′ temperature after ignition, then—

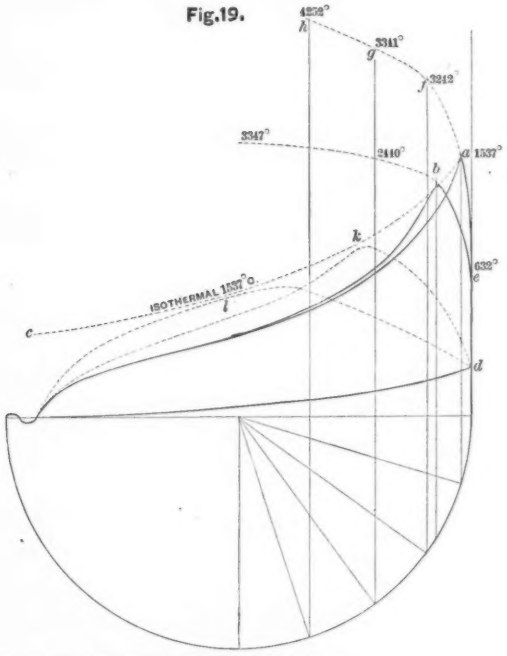
$$T' = \frac{P' \, T}{P}$$

both pressures and temperature absolute. In diagram Fig. 1 it was shown that the temperature of compression, corresponding to 40 lbs. above the atmosphere, was 150°.5 Centigrade, and from these figures the temperature 1,537° was obtained. This was the minimum possible temperature, as would be observed from certain considerations developed at p. 21. Whether the flame had spread throughout the mass of the mixture or not, this was the average temperature. From *a*, Fig. 19, was drawn an isothermal line, *a b c*, dotted; at the point *a* the temperature had commenced to fall, up to that point it had been rising at a very rapid rate. The semicircle drawn below the atmospheric line showed the path of the crank-pin, and each division represented in time one-fiftieth of a second; the engine was running at one hundred and fifty revolutions per minute when the diagram was taken. Comparing the condition of the gaseous mixture in one-fiftieth of a second before maximum pressure, and one-fiftieth of a second after maximum pressure, in the first one-fiftieth of a second the average temperature had increased 905° Centigrade, while in the second hundredth it had diminished about

189° Centigrade. Within a limit of one twenty-fifth of a second there was a point where the increase of temperature ceased, and where a fall of temperature began. What did this mean? Why did the increase of temperature cease in so sudden a manner and a fall of temperature set in?

From the point *d* to *a* the temperature had been increasing, this increase being due to the progress of the flame; at the point *a* the increase ceased, and a fall set in. Take the point *e*, then the average temperature was 632° Centigrade; from *e* to *a* the time taken one-fiftieth of a second, and the temperature rose to 1,537° Centigrade; in that time it had increased by 905°; suppose the same rate of increase to continue for another one-fiftieth of a second, the pressure would rise to the point *f*, and the temperature would be 2,442° Centigrade, the points *g* and *h* showed the effect of further increase. But the increase had abruptly ceased at the point *a*; from *a* to *f* the volume had changed so slightly that the rate of cooling could not have increased appreciably. The amount of work done in that movement was also relatively insignificant, and yet from some cause the increase of temperature going on with such rapidity, 905° in one-fiftieth of a second, had not only diminished, but an opposite effect had set in. It could not be supposed for a moment that the progress of the flame had been abruptly stopped by any cause other than completed inflammation of the whole mass. The flame which in one instant of time had been flashing through the explosion mixture had reached the enclosing walls, it had uniformly heated the whole combustible mass, and in the next instant the temperature began to fall; the law of cooling took effect. The very rapid rate of rise, and the abrupt change from rapid rise to slow fall of temperature, at a given point, showed that at that point completed inflammation had been attained. The cooling which was so slow as to be unable

Fig. 19.



Engine speed 150 revolutions per minute.
One division of circle=one-fiftieth part of a second at above speed.

to put an appreciable check on the rate of rise up to the point of maximum temperature, could not be supposed to suddenly increase to such an enormous extent as to completely absorb and overpower at that instant the effect of continual spread of flame. There could be no doubt that, as Sir Thomson had pointed out, on diagram Fig. 6, the maximum of the curve indicated truly the instant when the combustion was as complete as dissociation allowed it to be. It was certain that at this point of the diagram the flame had spread completely through the whole volume of inflammable mixture, and that in whatever way the sustaining of the pressure to nearly the adiabatic line was to be explained, it could not be accounted for on the hypothesis of a continued spread of flame.

A little consideration of the conditions of the indicated diagram would show that the slower the rate of inflammation, relatively to the movement of the piston, the less distinct would the point of maximum pressure become, and the more rounded would the apex of the diagram appear. Nevertheless the point of completed inflammation was easily determined from the point of maximum temperature, when near the end of the stroke this point might not be the point of maximum pressure. He had been careful to make this distinction, and had said, with reference to slow inflammation, p. 25: "This supposed phenomena has been erroneously called slow combustion; if it has any existence it should be called slow inflammation. It has a real existence in the Otto engine only when it is working badly; but even then maximum temperature is attained, and very distinctly marks the point of completed inflammation." On diagram Fig. 19 was shown the effect of increasing the speed of the engine while preserving a constant rate of inflammation. If the speed were increased from one hundred and fifty revolutions per minute three times, or to four hundred and fifty revolutions per minute, it would be found that the point *a* would be moved forward to *k* and *b* to *l*. In both cases the temperature attained would be nearly 1,537° Centigrade, a slight fall would be observed due to increased cooling surface and to a part of the work being done before maximum temperature was attained. But in all cases the maximum temperature marked the point of completed inflammation and the temperature began to fall so soon as it was attained. For ignitions attaining their maximum very late in the stroke, maximum pressure need not coincide with maximum temperatures; but a reference to the isothermal line showed the point of highest temperature. Using an inflammable mixture of constant composition, and varying the speed of the engine, it was always found that ignitions attained maximum temperature later and later in the stroke always came very near the isothermal line drawn from the point of highest pressure at the beginning of the stroke. The lines never ran over this isothermal. This meant that, whether inflammation was completed early or late in the stroke, nearly the same maximum temperature was attained. It followed from the relations between isothermal and adiabatic lines, that the lines drawn by the indicator from late ignitions always crossed those from early ignitions. This was shown by the diagrams taken from an Otto engine by Mr. Bousfield, for which he must thank that gentleman. In these diagrams, however, it was evident that the mixture used had not been of constant composition at all speeds. This would be evident by examining Fig. 15. When the speed had been changed from one hundred revolutions per minute in the larger diagram to two hundred in the smaller, the increased speed of the engine had caused it to take in a smaller weight of gaseous mixture, as was shown by the compression line leaving the atmospheric line later, and that the pressure on completion of the in stroke only rose to 22 lbs. per square inch instead of 30 lbs., as in the other. If the mixture had been the same the point of maximum pressure would have crossed in the first diagram at this point, and the pressure line would have run into the first lower down, as was shown in his diagram at *b*, Fig. 19. In the Otto engine the hot exhaust remaining in the space when each cycle was completed still further complicated the comparison between different speeds. At the higher speeds the walls of the cylinder had less time to cool the exhaust, and consequently the average temperature of the mixture before compression must be greater at high speeds. In his own gas engine this complication had no existence,

because the whole charge was replaced at every stroke. In Mr. Bousefield's diagram, Fig. 16, the same change of mixture was evident, but here the change of speed of the engine was relatively greater, and consequently the lower diagram crossed the upper one somewhat earlier. In Fig. 17 this was more and more evident; still no two of the compression lines coincided, showing the proportion of exhaust to inflammable mixture to be continually increasing, and the maximum temperature attainable by the ignition consequently becoming less and less. Even in diagram, Fig. 18, maximum temperature was attained, and could easily be discovered by calculating the average temperature at each point along the line of increasing volume. Mr. Bousfield stated that a light applied to the exhaust of an engine, giving diagram, Fig. 16, caused explosion, and from that inferred that combustion was not completed at the end of the stroke. He would find that when this happened the engine was missing ignition altogether and discharging the unburned contents into the exhaust. He might observe that the horizontal line in that diagram did not mean constant temperature, but indicated constantly increasing temperature. Mr. Bousfield has evidently fallen into the same error as Mr. Imray, and confounded low pressure with low temperature without considering the change of volume. It was a characteristic of the inflammation of a gaseous mixture in mass, that so long as inflammation continued to spread, so long did the average temperature increase. . Dissociation did not begin to sustain temperature until the temperature fell. In the construction of the theoretical diagram Mr. Bousfield had fallen into error. He drew from the points F G H, Fig. 14, to A L produced, lines which he described as adiabatics, and then said that the curve drawn through P Q R "represented the pressure at any time in the contents of the cylinder, supposing these contents remain confined in the space at the end of the cylinder, and not allowed to expand." Now the lines F G H should not be adiabatics but isothermals, as Mr. Bousfield's object in constructing the diagram was to get the time taken in a closed space to attain the temperature existing in the engine at the points F G H. The points L M N should show the pressure at constant volume at these temperatures. If Mr. Bousfield calculated the temperature from an actual diagram, he would find that maximum temperature coincided with maximum pressure when at the beginning of the stroke. He thought from his remaining criticisms that Mr. Bousfield had not understood the nature of the proof advanced in the paper, and that when he had studied the subject and appreciated the nature of the considerations advanced, he would admit the truth of the theory set forth in the paper.

It had been asked by Dr. Hopkinson whether the pressure rose higher when an engine was running slowly than when it was running fast? Whether the pressure attained on exploding a gaseous mixture in a closed space and in an engine was the same? Given the same proportion of gas to air and the same temperature and pressure of mixture before ignition, then the pressure attained after ignition was the same in all stages where the maximum pressure was attained at the beginning of the stroke; it was the same whether in a closed space or in an engine. But the ignition must be rapid enough at the higher rate of speed to give maximum pressure at the beginning of the stroke. As he had already pointed out, if an engine was to run fast enough it might overrun the rate of inflammation, and the maximum temperature would not be attained till towards the end of the stroke. If an engine was run at two hundred revolutions per minute and maximum pressure was attained at the beginning of the stroke, then however slowly that engine ran using the same mixture, the maximum pressure would always be the same, it would not increase. Dr. Hopkinson then asked, Was the maximum pressure the same in large and in small engines? When using a similar mixture, the same pressure and temperature before ignition, it was the same. In small engines the temperature fell more rapidly than in large ones because of the greater proportion of cooling surface to volume of gases, but the maximum pressure attained was nevertheless the same because of the rapid rate of ignition. The results obtained in the large cylinder to which he had alluded, and those obtained by Professor Bunsen in a small tube,

each showing a limit to the rise of temperature which could not be referred to cooling, and each showing complete spread of flame, proved that the maximum pressure to be obtained from an explosive mixture was independent of the dimensions of the vessel used. Dr. Hopkinson had asked why, in comparing types 2 and 3 of engine, he used different maximum pressures; why in the second type he used 76 lbs. per square inch above the atmosphere, and in the third over 200 lbs. per square inch. His reason was this: the three types were taken under conditions which have been found in practice to be the most favorable for each. He had compared the theory of these types of engine as nearly as possible under conditions used in practice It was quite true that type 2 should be compared with type 3 under similar conditions of pressure from a purely theoretic standpoint; but the object of the paper had been to inquire into the cause of the greater efficiency of the third type as in use against the two first also in use. It would be seen that to attain a pressure of 200 lbs. per square inch in type 2 it was necessary to compress the mixture to that pressure before ignition, the temperature of compression being nearly 365° Centigrade This involved considerable loss of heat in the reservoir, and increased the chances of leakage while compressing; in type 3 a pressure of 40 lbs. per square inch before ignition was all that was required to attain 200 lbs. after ignition. He believed that type 2 could work advantageously at a much higher pressure than 76 lbs. per square inch, but he questions whether it could do so at so high a pressure as 200 lbs. The advantage of type 3 in this respect was a comparatively low pressure before ignition. With careful workmanship doubtless it would be possible to use an engine of type 2, the theoretical efficiency of which would be quite as much as type 3, as given in the paper.

The description by Mr. F. H. Wenham of his work on hot-air engines was interesting, and his distinction of the cylinder itself as the heat generator or furnace was the essential one between gas and hot-air engines, and was indeed the great cause of success in these engines. Mr. H. Davey had objected to his comparison of the efficiency of gas and steam engines, and considered the basis of comparison of efficiency used by him as an unfair one. In comparing engines of the same system it was right, as Mr. Davey stated, to use as the standard the mechanical equivalent of the total available heat; but in engines of totally different nature the only basis of comparison was the number of heat units given to the engine, and the number of these heat-units converted into mechanical work. If one system was necessarily limited in range of temperature, as the steam engine was, then the inquiry must not be how near it approached perfection within that range, but how much heat could another system convert into work as compared with it. In comparing steam engines with steam engines Mr. Davey is perfectly right; in comparing with gas engines the general basis must be taken. He agreed that the speedy downfall of the steam engine was not to be anticipated; he only held that the gas engine was now in its infancy, that it contained greater possibilities than the steam engine, and that in the future it was certain to be in every way a great advance on the steam engine, and likely to supersede it.

The propriety of treating the gas engine as an air engine had been called in question, and he had been asked whether the specific heats of air and the gaseous mixture used were in any way comparable. The specific heat of air at constant volume was 0.169, and the specific heat of a mixture of 1 volume of coal gas and 12 volumes of air could not exceed 0.200, so that for the purpose of approximate comparison their adiabatic curves might be considered as nearly identical. So little was known of the specific heat of gases at high temperature that Mr. Clerk considered it simply an affectation of accuracy to endeavor to make the comparison closer. He was aware that the efficiency of a heat engine was independent of the nature of the fluid employed, provided the temperatures between which the engines worked were the same—that was provided there was the same difference between source and refrigerator. But this was just where the steam engine failed. Given equal amounts of heat from the same source, in the steam engine the high temperatures could not be utilized, because, first, a certain quantity of heat had to be expended to change the physical state of the water; and as the steam

produced was rejected as steam all the heat so expended was lost for the purpose of procuring high temperature. With air, on the other hand, the same quantity of heat from the same source, a much higher temperature was attained, and consequently a greater range of temperature due to work performed. The use of steam necessitated a limited range of temperature, and the discharge of all the heat used in converting water from a liquid to a gas. It had been argued that in engine type 2 he had over-estimated the efficiency, and made it greater than was possible from a perfect heat engine working between the limits of temperature used. Mr. Bamber had fallen into error by mistaking the limits, and in this he was not alone. This type of engine presented very interesting peculiarities in theory, which, so far as he was aware, had hitherto been missed by writers on thermo-dynamics. Although 1,537° Centigrade was the maximum temperature, and 1,089° Centigrade the temperature of discharge with the exhaust, yet these temperatures were not the limits within which the engine was working; the refrigerator, which was at atmosphere temperature 17° Centigrade, was being used to a certain extent without being apparent.

The diagram was not a simple one; the efficiency 0.36 was the result of the united action within two different limits. The diagram from 1,537° Centigrade to 1,089° Centigrade was the same both in types 1 and 2, and working between these limits the maximum possible efficiency was 0.247; but in type 1 this efficiency was not attained, because at 1,089° Centigrade the air had not the same density as before expansion, and some work had been expended in changing the volume to twice its original amount. If before heating the air had been compressed slightly, then heated to 1,537° and expanded to its original volume, and lowered in temperature due to work done to 1,089°, the duty would be 0.247. If in type 1 a condenser were used, and the temperature reduced to 17° Centigrade, the additional work obtained would raise its duty to 0.247, without this it remained at 0.21. In both types the efficiency between the limits 1,537° Centigrade and 1,089° Centigrade was the same; but in type 2 a considerable amount of work was obtained in the earlier part of the diagram, a certain amount of work was done on increasing temperature from 217°.5 Centigrade to 1,537°, and a considerable proportion of heat could be converted into work on an increasing temperature, still conforming to the law $\frac{T_1 - T_2}{T_1}$ as the maximum possible between the limits.

In type 2, to a certain extent, the refrigerator at atmosphere temperature was made available in a portion of the action, and consequently a portion of work done on increasing temperature, while the latter half of the stroke was accomplished on falling temperature. This was the reason why a greater efficiency was got than the apparent limits would allow. Mr. Bamber then argued that it made no difference whether it was necessary to use an air pump or not, if only the same quantity of heat were consumed and the same theoretic efficiency obtained. In practice it made all the difference; the great cause of failure with hot-air engines was not imperfect theory but very low available pressures combined with high maximum pressures. Nearly all the power indicated was used up in friction; in the earlier gas engines the average pressures were very low also. The advantages of compression were a high available pressure, small cooling surfaces, and small loss by friction. There the efficiencies depended on the range of source and refrigeration; but compression allowed all this to be attained under practical conditions. It was hardly necessary to explain that there was a certain maximum efficiency for heat engines. What he had shown in this paper was that a greater proportion of this was possible under working conditions with compression than without.

The parallel by Mr. Cowper between slow inflammation and imperfect admission of steam in a cylinder was very just, and illustrates the great loss of power and heat involved by imperfect mixing of gas and air, or by failing to attain maximum pressure as soon after firing as practicable. It was only by a constant application of theory to practice, and a constant testing of results obtained by varying conditions, that he had been able to produce the diagram which Mr. Cowper approved. The amount of gas consumed by his 6-HP. engine was 22

cubic feet per 1 HP. per hour. Of course in cost this did not stand comparison with the coal used by a large modern steam engine; the steam engine had greatly the advantage; but compared with a small steam engine it was economical. When gas was manufactured expressly for gas engines it need cost but little more than the coal used to produce it, and as the gas need not be illuminating all the carbon might be converted into gas. The gas might be in fact a mixture of carbonic oxide and hydrogen.

HOUSE DRAINAGE AND SANITARY PLUMBING.

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III.

PLUMBING FIXTURES.

The various plumbing fixtures which receive and deliver to the drain the foul wastes of the household, will be reviewed here only from a sanitary point of view. For more detailed technical descriptions of plumbing appliances I refer to the interesting series of articles on "Modern Plumbing," by T. M. Clark, Esq., in the *American Architect* for 1878, and to numerous papers on "Plumbing Practice" in the *Sanitary Engineer*.

Plumbing fixtures should be concentrated in a house as much as possible, so as to render necessary only few vertical stacks of soil and waste pipes, and to avoid long horizontal runs of pipes, which are objectionable inside floors, first, because they necessitate the cutting of beams; second, because they prevent the running of waste pipes with proper fall. Much may be effected in planning a new building in this direction by a proper attention of architects to its drainage system.

To householders and persons about to build a house I would give the general advice to have only few plumbing fixtures, as few as they can possibly get along with, but to have these of the very best quality and fitted up in the very best manner. It is much better to have only one water closet in a house, used constantly by all its occupants, and therefore frequently flushed, than to have half a dozen or more, each used only little.

It has recently been proposed by some, in view of the great danger to health from defective plumbing, to arrange all fixtures in an annex, separated from the living and sleeping rooms of the house. This would be not only inconvenient but impracticable in cold climates and seems entirely unnecessary. All that needs to be done is to remove plumbing fixtures from sleeping rooms, as sewer gas entering these through leaky joints or defective traps and fixtures, would be much more dangerous to persons inhaling it during sleep than during hours of active exercise. Wherever possible, it is desirable to locate water closet apartments and slop sink closets so as to be cut off from the main part of the house. This would involve the separation of the water closet from the bath room, such as is common in Europe, but little known in this country, and which arrangement I am inclined to favor, especially in the case of a house, occupied by a large family, and having only few plumbing fixtures.

If proper regard were paid to the ventilation of rooms, containing plumbing fixtures, the risk from sewer gas would be infinitely reduced. Unfortunately, it has hitherto been the habit with most people to care more for the bright look of their fixtures, for decorated china ware, costly marble slabs, silver-plated faucets, chains and tubs, for handsomely finished woodwork around bowls, water closets, sinks, than for the proper trapping and ventilating of such apparatus. Tight woodwork around bowls, tubs, sinks, slop hoppers and water closets, which is the rule in ninety-nine out of every hundred houses, forms harboring places for vermin; they in time accumulate dust and become ex-

ceedingly filthy, damp and foul smelling. The encasing of plumbing fixtures should be discouraged for sanitary reasons. Dampness and nasty odors can be prevented by keeping such spaces entirely open so that a free current of pure air sweeps around the fixtures, the most remote corner of which is thus made accessible to servants for cleaning purposes. But even with good sanitary appliances, properly ventilated and connected with self cleansing traps and waste pipes the householder should not forget that constant care and watching is imperative, as well as a thorough cleansing and scrubbing as often as once a week and preferably oftener.

Sufficient hints will be given in the following pages as regards the merits and defects of the various plumbing fixtures, especially the different types of water closets, to guide the householder in selecting proper and satisfactory appliances. In regard to the selection of a proper water closet—and, in fact, of every plumbing fixture—a certain embarrassment arises to every householder, in so far as almost every manufacturer naturally thinks his goods the best and safest to be used. Should the householder be unable to make a selection from his own judgment, he should consult an architect or sanitary engineer of reputation. Should he decide from personal opinion and examination of closets, let him bear in mind that closets almost without exception present a good and cleanly appearance in manufacturers' showrooms. The real test of the efficiency of a water closet is some months' severe use in a frequented place (which, however, should be under constant supervision of a janitor). In this connection I would advise to choose none but the very best apparatus for the use of the servants. A servants' water closet is likely to receive a rougher treatment and less cleaning than closets for use of the family; closets with movable machinery (pan, valve and plunger closets) are especially objectionable, as they frequently get out of order; no cheap kind of hopper should be used. An automatic flushing arrangement for servants' and children's closets will secure better cleanliness than arrangements to be worked by hand.

In speaking of water closets in general further points of importance for the selection of such apparatus will be mentioned.

WASH BASINS.

Beginning with wash basins, little of sanitary importance may be said with regard to them. If properly fitted with waste pipes of proper size and material and efficiently protected by a good trap, they may be considered perfectly safe conveniences in dressing rooms. Their use in sleeping apartments, and in closets or boudoirs near bedrooms without independent ventilation, is attended with considerable risk, and the habit of putting stationary lavatories in such rooms, which has become so general nowadays, should be earnestly discouraged, especially for such rooms, as are not continually occupied (summer residences, hotels, &c.).

Wash basins are mostly made in earthenware, this material being the cleanest and best for the purpose. Iron works, however, manufacture cheap iron washstands, plain, painted, galvanized, or enamelled, which may answer for office use, for prison cells, &c. Copper basins are rarely used.

Earthen bowls are attached by brass basin clamps to marble slabs, the joint between them being made tight by means of plaster-of-Paris. To prevent damage to ceilings the bowls are provided with a number of holes near the upper rim, leading to a short horn, to which the lead overflow pipe is attached. Some bowls have a "patent" overflow, a concealed channel in the side of the bowl.

The outlet of bowls is commonly closed by means of an india-rubber, brass, or plated plug, to which a chain is attached. The annoyance caused in lavatories of public places by too frequent breakage of the chain, necessitating the removal of the plug by placing the hands into the dirty water of the bowl used by some unknown person, has led to the invention of a number of valve wastes for bowls. In most of these, as for instance, McFarland's, Foley's, Boyle's valves and the Boston waste, the outlet is closed some distance away from the bowl, thus leaving the bowl in connection with the valve chamber, which, after each use, remains coated with soapsuds and foul slime. At the next use of the bowl the clean water will mingle with this

waste matter and become soiled even before use. Moreover, the valve chambers get more or less foul after use, and emit noxious smells into the rooms.

The only device which closes the bowl directly at its bottom is "Weaver's waste." By simply touching a knob, connected with a lever, the stopper in the bottom of the bowl is lifted and held in place.

Jenning's "tip up basins" also do away with chain and plug and are very convenient for use, as the basin is emptied by simply tilting it, thus discharging its contents into a bowl underneath, which is concentric with the upper basin, and to which the trapped waste is attached. It appears at first sight to be a cleanly device, but it gradually accumulates foulness in the lower basin, which receives no special cleansing, and for this reason tip up basins are not to be recommended, except where a stricter regard to cleanliness of plumbing fixtures is paid than is usual in most households.

The objection raised against most valve wastes for bowls, namely, that the walls remain coated with a more or less foul slime after emptying the bowl, is also true in regard to the bowl itself. In private houses these are, of course, well taken care of and daily cleaned; but in public lavatories, used rapidly in succession, a decided lack of cleanliness is felt. An entirely new departure in wash bowls, so far as this country is concerned —for it has been manufactured and sold in England—would be a *flushing rim lavatory bowl*, supplied with hot and cold water through a nozzle, to which both supply pipes are attached. By opening either faucet, hot or cold water, as desired would enter the bowl, simultaneously at all sides, and give it a thorough downward rinsing flush. The outlet of bowl may then be closed and the bowl filled with clean water. With such a flushing rim bowl some of the valve wastes would become unobjectionable even to the most fastidious.

To make the flushing rim lavatory perfect in neatness and cleanliness, the marble slab, to which the bowl is clamped, should be supported by handsome brackets, leaving off all carpentry underneath. The floor under the bowl and the rear wall may be neatly finished in white tiles, or in cement or terrazzo floor, so as to be impervious, thus doing away with the safe lining underneath the bowl. If tiling or a terrazzo floor is considered too expensive, a well finished hardwood floor should be used.

The arrangement suggested for fitting up lavatories applies equally to common bowls. Hitherto more or less tight woodwork has been used to encase the space under wash bowls in order to hide from view traps, supply and waste pipes, safe linings, drip pipes, etc. Such tight unventilated spaces with dark corners must necessarily accumulate dirt, and become damp from leaky fixtures, and nasty in general. With first class plumbing work it is unobjectionable to have lead pipes and traps in sight: leakage is easily detected, and cleanliness of servants better enforced where there is plenty of light and air around a wash basin.

BATH TUBS.

Bath tubs are made of wood, or wood lined with galvanized sheet iron, or with zinc or heavy copper, tinned and planished, or nickel plated, of cast iron with porcelain enamel, and of stone ware. Any of these may be used, the selection depending chiefly upon their cost and upon the personal preference of house owners. For private residences copper bath tubs are used more than any others, the weight of the copper being from 16 to 20 oz. per sq. ft. for the best tubs. Enamelled iron tubs are also used extensively, especially in hospitals, asylums, &c. The porcelain bath tubs, although perfectly non-absorbent, most cleanly and attractive in appearance are not much in use, being very expensive, heavy and clumsy.

For bathing establishments enamelled iron and copper tubs are not to be recommended. the former losing their enamel by continued use, the latter being easily knocked out of shape and requiring constant attention to keep on them a bright polish. In such places earthenware tubs will answer very well, being easily cleaned, and as they are used rapidly in succession they do not chill the water after the first bath, an objection raised sometimes against marble or porcelain tubs in private houses. Tubs in bathing establishments are often con

structed of brickwork, lined with slate, or with white tiles or marble flags.

Many devices have been introduced to do away with the chain and plug arrangement of tubs, which device gets unclean from soapsuds here as in the case of wash bowls. Such improved bath wastes are, for instance, Weaver's, McFarland's, Foley's, H. C. Meyer's, Jenning's, Stidder's and others. None of these is preferable to the "standing overflow," a most simple and cleanly contrivance, consisting of a tube of same bore with the bath waste pipe, with a trumpet-shaped mouth at its top, which tube is inserted in place of the plug at the bottom of the bath tub. It renders a special overflow pipe unnecessary. The only objection, sometimes made against it, is that it may be in the way while bathing, especially with short, so-called "French" bath tubs.

While it is not my intention to consider the supply of hot and cold water to fixtures in general, nor to discuss the relative merits of ground cocks, compression bibbs and self-closing faucets, I must briefly touch, for reasons that will appear hereafter, upon the manner of supplying water to bath tubs.

If the hot and cold water faucets are placed near the top of the tub, the hot water speedily fills the bath room with steam (although this can be partly overcome by using a double bath cock with only one supply inlet); the noise of the falling water is also sometimes objected to. To avoid this inconvenience the supply has been made to enter the bath, hot and cold water mixed, through the same hole that serves as an outlet for the foul water. Thus soapsuds and filth coating the waste pipe and left there from the time the bath was last used, mingle with the clean water. Such a device is unsanitary and must be utterly condemned.

If it is desirable to avoid the steam or noise in filling bath tubs, the supply inlet may be placed at the foot end of the tub, near its bottom. An advantage which this arrangement offers is that servants cannot draw water into pails or pitchers in a bath tub, a frequent cause of the chipping off of the enamel of iron tubs and the bruises made in the sides of copper tubs. It appears, however, that such a location of the supply inlet below the water line of the bath tub is, in certain cases, endangering the purity of the water supply. This risk always occurs wherever the bath tub is supplied directly from the rising main and the pressure of water is insufficient to supply at all times the upper stories of city houses. The *American Architect* of 1882, in calling attention to this danger (which danger is well known to exist in the case of water closets flushed directly from the service pipe), says, as follows:

"Thousands of fixtures are in daily use which are liable to have their supply fail altogether on certain days and hours, or to have it withdrawn temporarily by the opening of a faucet below. All such fixtures are exposed to the worst consequences of intermittent supply. If any person having access to fixtures so placed will try the experiment of opening a faucet at the time of low water, the rush of the air sucked back into the pipe will be plainly heard, or by placing the finger over the mouth of the faucet the inward pressure can be felt. Even where the head is considerable, an artificial lowering may be, and often is, caused by the opening of faucets in the lower stories, which will leave a vacuum in the pipe supplying the upper fixtures, and in such cases substances near the mouth of the upper faucets are liable to be sucked through them into the supply pipes. We have known the opening of a pantry cock in a lower story to siphon out in this way and discharge into the pantry sink the entire contents of a bath in a room above, much to the amazement of its occupant. The bath happened to be fitted with a bottom supply."

This may even happen with a supply from a tank in the attic, and the only means to prevent the occurrence would be to run special lines of hot and cold water from boiler and tank respectively to the bath inlet, or else to place a check valve in the cold water supply to the bath, which remedy, however, cannot be relied upon to work for ever.

There are many varieties of tubs, used for personal cleanliness, such as foot tubs, hip baths, bidets, shower baths, &c. They need no further explanation, as the principles for the sanitary construction of bath tubs apply equally well to them.

Bath tubs of wood, lined with metal, necessarily require some exterior finishing woodwork, which also serves to hide

from view the supply pipes, the overflow, trap and waste pipe.

In Europe, metal bath tubs are made sufficiently heavy to stand without a casing. This method of fitting up bath tubs has much to recommend it from a sanitary point of view; such bath tubs stand free on the floor, perfectly accessible and with all pipes in sight, which seems entirely unobjectionable. Iron porcelain lined bath tubs are sometimes left without woodwork in our hospitals and asylums and give complete satisfaction.

LAUNDRY TUBS.

Laundry tubs are made of various materials, such as wood, wood lined with sheet lead, enameled or galvanized cast iron, cement stone, soap stone or earthenware. Wooden tubs are objectionable as this material readily absorbs the dirty water and becomes foul, emitting a close odor when not in use. Being alternately wet and dry they are liable to leak and will quickly rot. Cement stone laundry tubs are cheap, durable and cleanly. They have no seams, each tub being manufactured in one piece, and therefore will not leak. Galvanized or enameled iron and soap stone trays are equally good and much in use. The white crockery or "ceramic" tubs are undoubtedly the neatest, and are always perfectly clean and sweet. They are not subject to wear or leakage, nor do they absorb dirty water, and therefore do not become foul from use. They are, of course, more expensive than any of the others. Woodwork about wash tubs should be dispensed with as much as possible, and the tubs treated in this respect as suggested in general for plumbing fixtures.

KITCHEN AND PANTRY SINKS, LAUNDRY AND HOUSEMAID'S SINKS.

Sinks are made of wood, of wood lined with lead, or with copper, of cast iron, which may be galvanized or enameled, of copper, soap stone, slate or earthenware.

For pantry sinks tinned and planished copper is generally used, being preferable to porcelain or soap stone sinks, as glass and crockery is not as liable to breakage in them.

For kitchen and laundry sinks soap stone or iron is much used. Galvanizing or enameling the iron much improves the appearance of the sinks, but even these protective coatings wear off in time, and then the iron rusts rapidly. Of late earthenware sinks have been manufactured up to large sizes and are undoubtedly the cleanest and neatest of all kinds.

Housemaids' sinks, used only to draw water, may be of small size and look most cleanly when manufactured in earthenware, although other materials are often employed.

Sinks should be provided with strong, metallic strainers, either open or plug strainers. In both cases the strainer should be securely fastened to the sink so as *not to be removable* by servants, in order to prevent obstructions of the waste pipe and trap. With plug strainers it is important that the sink should have an overflow pipe of sufficient capacity to carry off the full supply, in case the supply cock should be accidentally left open.

In most houses kitchen sinks are encased in tight woodwork, and consequently a close, damp and foul smell is often noticeable in the compartment under a sink. This method of fitting up sinks is decidedly objectionable, and the common practice of using such unventilated closed spaces under a kitchen sink for the storage of kitchen utensils, or what is worse, cleaning rags, etc., should be strongly condemned. The space underneath a kitchen sink should be free to light and ventilation, and readily accessible for frequent cleansing. The sink may be supported by brackets, properly fastened to the walls, or it may rest on legs. The floor under the sink and the rear wall may be finished with white Minton tiles, which makes a neat and most cleanly arrangement.

The remarks just made as to the desirability of keeping the spaces under sinks entirely open apply also to pantry sinks and housemaid's sinks.

GREASE TRAPS.

Through kitchen and pantry sinks a large amount of grease, derived from washing dishes, etc,, is emptied into the drainage system. This grease proves to be of all the waste matters in the house the most difficult to deal with. Being dissolved by hot water it passes the strainer of the sink in a fluid condition, but soon becomes chilled, adheres to the

sides of the waste pipes or drains, lodges in traps, and becomes putrid and offensive.

If the drain inside and outside of the house has a very good pitch, the grease will probably be carried far away from the house before becoming solid. This is more likely to happen where sinks have plugged outlets, as the rush of the water carries the grease very far. The ammonia of urine will remove grease, and thus pipes receiving above the point where the waste from the kitchen or pantry sink enters the cellar drain a water closet or urinal discharge are often found to be comparatively free from grease.

But in large houses, or hotels, &c, the grease should not be allowed to enter the house drain at all; it should be intercepted by a proper grease trap, placed as near to the sink as the locality may permit. The grease trap may be placed either *within* the house, in the basement or directly underneath the sink, or else *outside* the house. The latter arrangement is much the best, provided the distance from the kitchen sink to the grease interceptor is not too great, otherwise the grease would congeal on its way to the interceptor. A circular tank made of bricks, laid in hydraulic cement, should be constructed of dimensions depending somewhat upon the size of the house. It should be large enough to allow the water time to cool. Its overflow pipe consists of a quarter bend, or better, of a T branch, dipping at least six inches below the water line, in order not to disturb the grease in the intercepting tank. *This grease trap should be frequently cleaned and inspected.* The grease, floating on top of the water, can easily be removed. Efficient ventilation by a large vent pipe should be provided. Wastes from kitchen and pantry sinks only should discharge into the grease trap.

If inside of the house and in the basement, the grease trap may be made of earthenware, of wood lined with heavy lead, or of copper. But such a grease trap in the basement cannot be recommended.

If directly under the sink it may be made of enameled or galvanized iron, of copper or of crockery ware. A number of patented sinks have an iron receptacle for grease immediately below and attached to them. It is doubtful whether these tanks under sinks can be made of sufficient size, without becoming clumsy, to allow the grease to cool and congeal. Unless properly attended to—and the kitchen sink is liable not to be kept perfectly clean by the servants—grease traps inside of a house constitute, in my opinion, cesspools on a small scale, holding fatty waste matters which readily become putrid and offensive. If there is no convenient place for an outside grease trap, better use none at all and trust to the action of the alkalies to "cut" the grease in the pipes. A valuable cleansing agent for pipes, where the use of a grease trap is omitted, may be found in occasional flushing with hot solutions of common washing soda, or better, of potash.

SLOP SINKS AND SLOP HOPPERS.

We have hitherto considered only those fixtures which receive foul water unmixed with discharges from the human system. Slop sinks and slop hoppers, as well as water closets and urinals, intended to convey to the drain these foul discharges, are more liable to become filthy outside and inside, unless carefully attended to.

Slop hoppers are provided on bedroom floors to enable servants to empty chamber slops into them. They must be flushed, after each use, by a sufficient quantity of clean water from a cistern, or else at frequent intervals by automatic flush-tanks, to expel the foul water from the trap and to wash the inner sides of the hopper bowl or sink. Considering the character of the foul water poured into such vessels, an efficient flush is fully as necessary for them as it is for water closets or urinals.

Slop sinks are made either of enameled cast-iron or of earthenware. Their outlet should always be provided with a fixed strainer to prevent any obstruction of the trap or the soil pipe by carelessly introduced articles, such as scrubbing brushes, etc.

Instead of a deep sink a combination of a sink and a hopper, such as Merry's slop-hopper sink, is sometimes used, and, if provided with a strainer, it will answer very well.

An earthen bowl, with improved flush-

ing rim, placed on top of an iron or lead hopper, will make a cleanly device. The neatest arrangement is a slop sink, made in one piece of earthenware, enlarged at the top to a square sink, and provided with a flushing rim and liberal supply of hot and cold water.

Slop sinks and hoppers should be treated in their external finish similar to kitchen sinks and water closets. Air and light should find easy access to them; there should be no tight woodwork around the apparatus with the usual amount of dust and untidiness. The floor may be of white tiles or of cement, and the walls may be laid with tiles or with enameled bricks.

If water closets without movable parts (hopper and washout closets) are fitted up without woodwork (except the seat) they may also serve the purpose of a slop sink, provided that the flush is not forgotten after emptying slops. The practice of using pan, valve or plunger closets, to get rid of chamber slops, is decidedly objectionable. These closets are most always encased in woodwork, which becomes impregnated with the foul water, carelessly emptied and often spilled. In the case of valve closets, the overflow pipe from the bowl is fouled and the same is true for plunger chamber and overflow of plunger closets.

URINALS.

No fixture is so liable to become unclean and foul smelling as a urinal, owing to the rapid decomposition of the urine. A small amount of urine spattered over is apt to become quite offensive. Urinals, therefore, require a very liberal amount of flushing water, running either in a constant stream, or else delivered automatically through flush tanks at frequent intervals. The material for urinals should be non-absorbent and non-corrosive.

Swinging and lipped urinals have been much used in modern private residences, but I should certainly advise doing away with them entirely, as a properly constructed water closet may safely take their place.

For offices, however, and public places, such as hotels, schools, railroad depots, places of amusement, etc., they become a necessity, but should be under constant supervision of a conscientious janitor, and should receive a thorough cleaning with hot water and soap, at least once a week, and preferably oftener. The ventilation of urinal apartments should also, for reasons stated above, receive careful attention.

Three kinds of urinals are in use, viz.: single lipped bowls, fastened along a wall, or in corners, and generally known as "Bedfordshire" urinals; urinal troughs and round urinals.

Lipped urinal bowls are made in earthenware and of enameled iron; the latter, however, cannot be recommended, as the enamel is apt to scale off, leaving the iron to corrode quickly. A number of porcelain lipped urinals is frequently placed along a wall, with board, slate or marble partitions between them. They are sometimes flushed by a stop-cock, to be turned by hand, which is an unsatisfactory device. Not only is the opening of the stop-cock frequently neglected, especially in public places, but a flush directly from the supply pipe will, in most cases, be insufficient thoroughly to rinse the sides of the urinal. If located in upper stories, the pressure is at times insufficient to fill the pipes, and air, possibly tainted and filled with disease-breeding germs, may be sucked into the supply pipes, on opening the stop-cock.

A much better flush can be obtained by supplying flushing water to the urinal from a special cistern, worked by chain and handle. For public places, however, where urinals are mostly used, I consider an automatic arrangement as being much superior. This may be accomplished by operating the flushing cistern from the door leading to the urinal; or else a treadle-action flushing apparatus may be used. Both arrangements are liable to get out of order, and preferable to either is a siphon tank, such as Field's annular siphon, or Guinier's siphon tank, and tilting tanks, such as McFarland's tank and others.

Modified forms of the Bedfordshire urinal have recently been manufactured both in England and in this country, which seem to possess many advantages over the common forms, the bowls being shaped so as to hold water (similar to a wash-out closet) to a certain depth. Such improved urinals are, for instance, Stidder's urinal and the Armstrong

urinal. With them the urine is immediately diluted with water, and consequently it is much easier to keep the bowl clean by frequent automatic flushing.

Urinal troughs are made of wood lined with lead, or of galvanized or enameled cast iron, or else of slate.

Round urinals are adapted to out-of-door location, in parks, etc.; they have a large circular bowl, holding a body of water, with a number of projectile lips around its circumference, separated by suitable slate partitions.

A constant stream of water should trickle into trough or round urinals, in order frequently to change the water in the bowl, and to secure an immediate and thorough dilution of the urine.

A modification of the trough urinal is sometimes constructed as follows: The back wall of the urinal apartment is suitably prepared so as to be impervious and non-absorbing. No material is better than slate for this purpose. A horizontal supply pipe is fastened to the wall about five feet from the floor, running from one end of the trough to the other. It is provided with a large number of openings, or sometimes with a water spreader, from which the water is constantly trickling down the walls. The floor should be made equally impervious, and should have a gutter with sufficient fall to carry off the water mixed with urine. The whole floor should be constructed sloping toward this gutter. Suitable stands or gratings are sometimes provided at the stalls, which are separated by marble or slate partitions. The outlet in the gutter must be provided with a strainer to prevent obstructions of the trapped waste pipe attached to it.

WATER CLOSETS IN GENERAL.

The most important and useful plumbing fixture in a house is the water closet.

Water closets should be in all houses that make any pretentions towards convenience. That they are a vast improvement over the old-fashioned, offensive privy vault in the back yard, everybody will acknowledge. But it is equally true that, unless of a good pattern, properly fitted up, properly used, carefully watched and frequently cleansed, they may become not only the sources of foul smell but also the cause of disease.

Leaving aside the question of the pollution of the soil and of well waters, of which the privy vault must sooner or later be the cause, it is in itself a nuisance and an abomination. In cold weather and during rain storms persons are liable not to use it when they ought to, and trouble of the digestive organs is sure to follow, as every physician knows. This is especially the case with females and with delicate children. Sick persons and invalids may suffer severely from exposure to the weather. Add to this the often unbearable stench emanating in hot weather from such vaults, and it will be readily seen how superior in point of convenience, health and cleanliness an indoor water closet is.

There are other improved devices for receiving fæcal matters, such as earth closets, ash closets, tubs or pails, which are far preferable to privies, and should be recommended wherever water is scarce; but these do not properly belong to my subject, which refers only to the "water carriage" system.

There is an endless list of water closets, and each year increases the number of newly invented and patented articles. It is, of course, impossible, nor is it even desirable, that my paper should give a complete description of all of them. I shall limit myself to describing the chief features of the various *types* of closets, mentioning a few examples of each type.

After reviewing the different patterns of water closets in use we shall speak of the general arrangement of the water closet apartment with respect to light and air.

The essential points to be considered in examining water closets are: the shape of the bowl or vessel receiving fæcal matter; the apparatus for discharging the contents of the bowl; the manner of trapping the water closet; the manner of flushing the bowl and trap; and the ventilation of the water closet.

The less *surface* a water closet has *exposed to fouling*, the cleaner and better will it be. All foul discharges should pass into water as quickly as possible. Thus the fouling of the sides of the ves-

sel will be efficiently prevented and the water will have a tendency to deodorize the excrements. All water closets holding a large body of water in the bowl (valve and plunger closets, wash-out closets and latrines) have this advantage. In other closets, where the body of water is in the trap (hoppers), this latter should be as near as possible to the bowl (short hoppers are preferable on this account), and the rear side of the vessel should be designed nearly vertical and straight to prevent foul matter from soiling the bowl before passing into water.

A further requirement is *durability and simplicity of the working apparatus.* The less moving parts a water closet has the better will it be. We must have regard to the rough usage to which such fixtures are sometimes subjected, especially in public places. Complicated or delicate mechanisms frequently get out of order, or fail to work properly under children's or servants' hands. Nobody will deny that, so far as this point is concerned, hopper and wash-out closets are vastly superior to pan, valve and plunger closets.

Each water closet should be separated from the drain or soil pipe by an *efficient trap*, placed either above or below the floor, and protected, whenever necessary, against siphonage. I consider one good trap as entirely sufficient, and do not have much faith in the additional water seal afforded by the water in the pan of a pan closet, or the water in the bowl of a valve or plunger closet. The copper pan quickly corrodes through the action of sewer gas in the container, and the flap valve gets leaky in time, while with plunger closets flushed from a cistern the bowl may lose its water if the outlet is imperfectly closed, as may happen, when paper remains clinging to the seat of the plunger. Wash-out closets are sometimes provided with a double trap, which is an obstacle to a proper flushing, and which may accumulate filth in the hidden and mostly unventilated space between both traps. I consider a double trap as unnecessary here as on the main house drain. Wash-out closets, the basin of which is shaped so as to form an efficient trap, and short hopper closets with trap above the floor, should not have a second trap (of either iron or lead) underneath.

The contents of a water closet trap should be thoroughly changed at each use of the closet, which can be accomplished by an efficient and liberal flush. This leads us to consider the supply of water to such apparatus.

A water closet should have a *copious supply* of water completely to wash at each use the bowl and trap as well as all surfaces coming in contact with foul matter. I do not, however, wish to be understood as favoring *reckless waste*, for it is well known that allowing the water to run continuously through a water closet cannot be regarded as *flushing*. Two or three gallons properly applied at each use will cleanse a water closet more thoroughly than an uninterruped trickling flow of water. In order to be efficient the *flushing water should come down "in a sudden dash."* To make the flush effective the supply pipe from cistern to bowl should be of large diameter, never less than one inch, and increasing up to 1½ inches as the head (or height of bottom of cistern over the bowl) diminishes. The force of the flush largely depends upon the shape of the bowl and upon the head of water available in each case. With closet bowls, circular in shape, a flush introduced in the direction of the tangent will whirl around its circumference, losing its force without effecting much cleansing. An oval bowl provided with a fan flush is a vast improvement. The best bowls are those provided around the upper edge with a proper "*flushing rim*," into which the water from the supply pipe enters simultaneously at all sides, and is directed to rush vertically downward, thoroughly washing the sides of the closet and rel taining sufficient force to expel the fou contents of the water-closet trap.

The mode of flushing a water closet from the main supply pipe of the house is decidedly objectionable, especially with closets located in upper stories of city houses. If water is drawn from a faucet in the basement the pressure is often reduced so much as to create a slight vacuum in the upper part of the pipe. If the valve of a water closet happens to be opened at such times, air, if not foul matter, rushes into the pipe from the bowl. Thus the purity of the drinking water is endangered, while the closet remains without a flush. This risk can be par-

tially avoided by the use of a check valve on the supply pipe to the closet valve. Such check valves, however, are not reliable and often fail to shut properly.

Water closets should be flushed from cisterns, never directly from the main supply pipe. But cisterns intended for storage of water to be drawn for drinking and cooking purposes should not be used for flushing water closets. In all cases the use of a *special cistern* for each closet or for a group of closets is recommended. Such water closet cisterns are manufactured in great variety by almost all water closet makers.

They are supplied with water either from the rising main or the large tank in the attic, by ball-cocks, made sufficiently strong to withstand the maximum pressure of water. In their simplest form cisterns have only one compartment, with a pipe attached to their bottom, leading to the closet, and with a valve closing this outlet of cistern, operated by a chain and lever. An overflow pipe is provided to prevent accidents through leakage of the ball-cock. Such tanks are only adapted for hopper closets, and should not be used where water is scarce, as with them a large waste is likely to occur.

Closets, holding water in the bowl (pan, valve, plunger and washout closets) require an "after flush" to refill the bowl, and the cisterns should be provided for such purpose, with a service box, holding a certain quantity of water. The outlet from cistern to service-box must be closed by a large sized valve in order to secure a quick filling of service-box.

Cisterns, arranged with a view to prevent the waste of water, are desirable wherever the water supply is apt to become scanty during the hottest and coldest months of the year. They have, in this case, three compartments, a large tank, supplied by a ball-cock, a measuring cistern, holding the quantity of water fixed for each flush, and a service-box for the after flush.

Water waste preventers for hoppers, however, require only two compartments, the receiving tank and the measuring cistern.

Water closet cisterns are operated either by the common pull-up arrangement, a handle being connected to one end of a lever, the fulcrum of which is firmly secured to the floor, while the other end of the lever is connected by a brass safety chain to the lever operating the cistern valve. Such an arrangement is common for pan, valve and plunger closets. Or else the lever and valve is operated directly by a chain, with tassel or ebony handle, which arrangement seems best adapted to hoppers and washout closets (and slop sinks).

An automatic "seat arrangement," in other words, the operating of the cistern by a depression of the seat through the weight of the person seems most suitable for public places, schools, factories, &c., where people using the closet are apt to forget to attend to the flushing. With the seat arrangement cisterns with double compartments and double valves must be used. A service-box is attached to the cistern for closets requiring an after flush. The depression of the water closet seat opens the valve from cistern to measuring box, which quickly fills up: relieving the seat of its weight causes the valve to close, and the outlet of measuring box to be opened, allowing the contents of the latter to rush into the water closet bowl. As the valve closing the outlet of the measuring box is of large size (generally 4 inches) the water rushes into the service box quicker than it passes out through the $1\frac{1}{4}$ or $1\frac{1}{2}$ inch supply pipe, thus securing to the bowl the after wash.

The annoyance frequently caused by the leakage of such cistern valves has led to the invention of other forms of water closet cisterns. Many of these are made to empty by siphons, such as Bean's flushing cistern, Purnell's patent siphon water waste preventer, Emanuel's double siphon water waste preventer, Braithwaite's siphon cistern, Brazier's cistern and others.

Bean's flushing cistern, lately introduced into this country, is very simple and efficient in its action. It contains an annular siphon, very much like Rogers Field's siphon. The inner limb (usually of cast iron) is firmly fastened in the center of the cistern, passing through its bottom, where it is connected with the supply pipe to the closet bowl. The outer limb, made of copper, with a dome head, allows of a vertical movement around the inner limb, this movement being effected by a lever, working in a slot, one end of which is attached to the outer

limb of siphon, while the other carries at its end a counterweight. A chain is attached to that extreme end of the lever holding the siphon, and the cistern is operated by a handle attached to the chain. By suddenly pulling downward the copper limb of siphon, water is forced over the top of inner limb and the siphon started at once. The outer limb is held down by the suction until all water is discharged, when the counterweight brings the siphon into its original position.

The tank is supplied with water by a ball-cock, rising with the water; the inner limb serves as overflow pipe and renders a special pipe for that purpose unnecessary.

Bean's tank provided with an $1\frac{1}{4}$ to $1\frac{1}{2}$ inch pipe to bowl is well adapted to flush earthenware flushing rim hoppers and slop sinks.

The double-siphon water waste preventer of Emanuel, London, is a cistern having two compartments, and a siphon of bent pipe, the shorter end of which opens near the bottom of the first compartment, while its large limb is carried to the closet bowl. The other compartment contains a smaller siphon pipe, the shorter limb of which opens into it, while the long limb is connected to the longer limb of the large siphon. Both siphons are started by forcing down a disc in the first named compartment connected to the lever, operated by chain and handle. This action forces water into the larger siphon, which quickly discharges the water contained in one compartment the while second siphon delivers as an "after flush" the water of the other compartment.

Purnell's water waste preventer is a plain cistern, provided with a common siphon pipe, the longer limb of which passes through the bottom of cistern and leads to the water closet bowl. Near the bottom of cistern a branch pipe leads into the longer limb, reaching to within a few inches from the level of water in the cistern, where it is closed by a valve. This valve is attached to one end of a lever, the other end of which is operated by a chain with handle attached. To flush the closet, the chain is pulled, opening the valve, and thus water flows through the connection pipe into the longer limb of siphon, causing a partial vacuum, which starts its action. The siphon continues to discharge until the contents of cistern are withdrawn, when it completely breaks. This cistern and Bean's do not give (in their usual shape) an after flush, and are consequently only suitable for hopper closets, slop sinks or urinals. Bean's tank, however, can be modified to give this after wash, where desired.

Among automatic arrangements for flushing water closets I mention flush tanks, working on the principle of the siphon, or tanks working by gravity. They are useful in railroad depots, schools, large factories, places of amusement, and in exposed localities, where standing water would be apt to freeze. Such tanks collect a continuous driblet from the supply cock until filled, their capacity being proportioned to the number of closets, and then discharge the full contents at once into the bowl (see chapter on flushing appliances).

The question of ventilation of water closets will be referred to later in speaking of the general arrangement of water closet apartments.

A properly trapped water closet, provided with a good flush from a special cistern, with a flushing-rim bowl of improved shape, located in a well ventilated apartment, judiciously used and well taken care of, should be inoffensive to sight or smell.

Bearing in mind the general principles just stated, we will now examine the various types of water closets. There are six distinct classes viz.: *pan closets, valve closets, plunger closets, hopper closets, washout closets* and *trough closets* (*latrines*).

These types are illustrated in Fig. 4 and Fig. 5. The closets shown, however, are not intended to illustrate any manufacturer's special make; they merely represent the various *types of closets.*

A shows the pan closet, flushed by a valve, supplied directly from the rising main, its bowl being closed by a pan, held in place by the counterweight, the closet outlet being trapped by a large D-trap under the floor.

B is an illustration of a valve closet, with cistern flush, the bowl having improved flushing rim and a special trapped overflow pipe, and being closed by a flap valve held in place by the counterweight; the container is provided with an escape pipe for foul gases, and the S-trap under

the floor has a vent pipe attached to prevent the loss of its water by siphonage.

C is a plunger closet with improved flushing rim bowl, supplied with water from a cistern, the outlet of the closet

by more or less complicated machinery, the three following types are free from any movable parts.

D is a long flushing rim hopper having an S-trap under the floor.

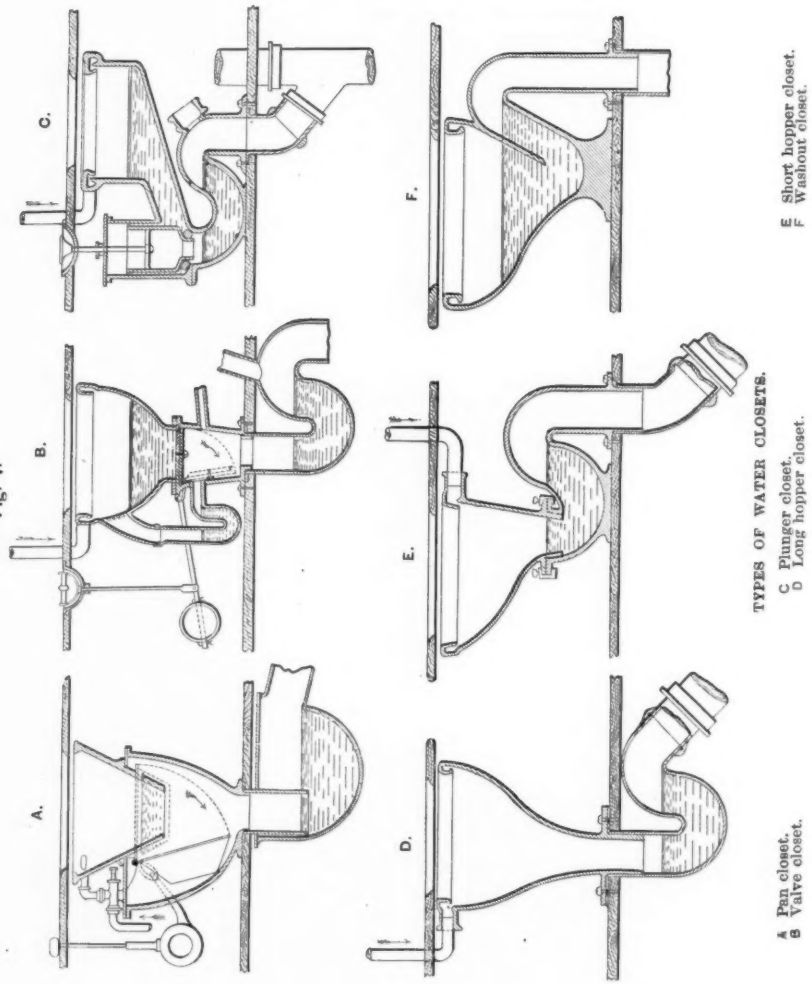


Fig. 4.

being on one side and closed by a plunger working in a chamber and to be operated by knob and pull. The trap is above the floor and provided with a hub to attach a vent pipe.

While these three closets are operated

E is a short flushing rim hopper with S-trap above the floor.

F is a washout closet, holding water in the basin, which also serves as a trap.

Fig. 5 shows the general characteristics of a trough closet (latrine).

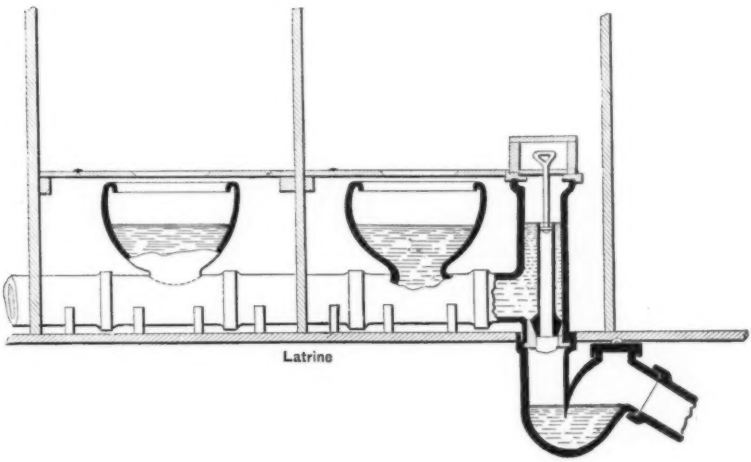
PAN CLOSETS.

To this class of closets belong the Philadelphia valve closet, the Bartholomew valve closet, Harrison's "Empire" water closet, Carr's "Monitor" closet, the Lambeth pan closet, Underhay's pan closet, Banner's closet, Craigie's "Eureka" closet, Craigie's "Century" closet and many others.

The name "valve" closet is an improper one, and leads to confounding these closets with those of the second type. The name is derived from the usual manner of supplying the flushing water to the closet, by joining the supply pipe to a more or less slow shutting valve, worked by the pull or handle of the closet. These valves are mostly unreliable, wear out and leak, especially when subjected to varying pressure from the street main. Pan closets may, however, be flushed by a special cistern with lever arrangement, and therefore the above serious defect is not one characteristic to these kind of closets.

The real defects of the pan closets will be at once apparent by inspection of Fig. 4. A. The excrements are received in a bowl, closed at the bottom by a copper pan, holding a few inches of water and forming a seal against the air from the container. The contents of the bowl or pan are discharged by tilting the pan by means of a lever, while a flush is simultaneously started. This pan works in an iron receiver or "container," upon which the bowl is usually fastened with putty. The outlet of the receiver is trapped by the common S-trap, although it is not uncommon to find in old houses a D-trap under the water closet, a second "container" of foul matters. The foulest part of the pan closet is the receiver, for the solids gradually accumulate on its sides, as these receive no washing from the flush. The filth soon undergoes decomposition, and the resulting gases, having been confined by the double water-seal of the pan and the trap, are expelled into the apartment at each use of the closet. They also frequently find an exit at the hole, through which the spindle, tilting the pan, passes. And finally, the putty joint between bowl and receiver may become untight and afford means for the passage of sewer gas. The flush is insufficient in most pan closets to clean the bowl; it certainly loses all its force before reaching the container, foulness accumulates here and excremental matter lodges in the trap, as the flush is not strong enough to drive it out through the dip or water-seal.

Fig.5



Some of the enumerated defects may be obviated by enameling the inside of the cast iron receiver; by ventilating it by an inlet pipe for fresh air and a vent pipe; by having special flushing arrangements for the container; by using a bowl with an improved flushing rim or a fan spray, the water for the flush being derived from a special tank. But by all these costly improvements the *only* merit of the pan closet, its cheapness, is annihilated, and a better water closet may as well be used. As long as a house is fitted with pan closets, of whatever pattern, it may be said not to have reached the standard of safety from a sanitary point of view.

VALVE CLOSETS.

To this class belong the following water closets: The old "Brahmah" closet, Hellyer's improved valve closet, the Lambeth valve closet, Tyler & Sons' patent valve closet, Underhay's valve closet, Bolding's "Simple" valve closet, Carr's American "Defiance" closet, Mott's "Climax" closet, Mott's "Whirlpool" closet, Demarest's "Acme" closet, the Alexander water closet, the "Victor" sanitary valve closet, the Lambeth trapless closet, Tylor & Sons' trapless closet, Bean's valve closet and others.

The valve closets (Fig. 4. B) are certainly a vast improvement upon the pan closet. Instead of being closed by a pan, the bottom of the bowl is closed by a flap-valve, from which the closet takes its name. This valve is tightly held in place by a counterweight on a lever to which the pull is attached. By lifting the pull, the valve, which is hinged, is turned downward, and allows the contents of the bowl to drop into the trap. The container is much smaller than in the case of pan closets. It generally has a ventilating pipe to remove foul gases. The bowl holds a large quantity of water into which the solids are dropped and instantly deodorized. It is provided with some of the best closets of this type, with a superior flushing rim, and is flushed by a special cistern. As the flap closes tightly against the bottom of the bowl this must be provided with an overflow which should have a trapped connection to the container. Unless some water is furnished to this trap at each flush it is liable to lose its seal by evaporation, thus establishing a direct connection between the container and the atmosphere of the water closet apartment. Such driblet to the trap of the overflow is supplied at each flush in the better valve closets. There is some danger of the fouling of the container. To prevent this the better closets have the inside of the container enameled, and as a larger body of water rushes from the bowl through the container at each discharge, the danger is much less than with the pan closet.

If such closets are flushed from a valve the solids will be driven out of the lead trap only after repeated flushing Better closets of this class have suitably arranged cisterns, which deliver quickly a large body of water to bowls with improved flushing rims, and thus the danger from foul matter being retained in the trap is much reduced. After continued use the flap-valve is liable to leak; excrements or paper may stick to it and prevent its tight closing, and all water will leak out of the bowl. Thus the additional water-seal is lost and the bowl is more liable to become fouled.

The Lambeth and Tylor's trapless closets are different from those just described. The outlet of their bowl is placed at the side, not at the bottom, and is closed by a vertical flap valve hinged to spindle and lever, and held in place by a counterweight.

Such valves may be less liable to be fouled with solid matters and may close more tightly on this account. The water rushing out of the bowl in a large body will effectually flush the outlet of closet.

Both closets do away with the trap and rely for exclusion of sewer gas only upon the flap-valve and the water in the bowl. In speaking of traps under fixtures I have already stated that each fixture should have a trap, and I would much prefer dispensing with the additional water-seal in the bowl than with the trap underneath the closet. Such trapless closets are not safe, for should the mechanism of the flap-valve get out of order the house would be entirely open to the invasion of sewer gas from the soil pipes.

PLUNGER CLOSETS.

Among closets of this type I mention Jenning's closets, the Demarest closet Mott's "Hygieia" closet, Moore's closet

Zane's "Sanitary" closet, the California "Perfection" closet, Myer's Gale closet, Myer's China closet, the Hartford Glass closet, Myer's egg-oval water closet, Smith's "Arizona" plug water closet, Pearson's Twin basin closet, Smeaton's trapless water closet, Smeaton's "Eddystone" closet and others.

The characteristic detail of all these (see Fig. 4 C) is the plunger closing the outlet of the bowl, which is placed at the side of the closet. The foul matters drop into a large body of water in the bowl, are therefore partly deodorized and easily removed from the bowl. By lifting the plunger the contents of the bowl are rapidly discharged into the soil pipe, and the rush of the water, leaving the bowl, is so great as effectually to drive all matters through the dip of the trap. The latter must be efficiently protected against siphonage, which is more likely to occur with plunger closets than with the pan, valve, or hopper closets. The danger with closets of this class lies in the fouling of the plunger chamber. Waste matters and paper may stick to the seat of the plunger or to its sides; the outlet will then be imperfectly closed, allowing the water to leak out of the bowl. Closets having a small plunger chamber are the better ones, not only because they will be cleaner, but because with large chambers the waste of water must necessarily be large.

Plunger closets flushed by a special cistern require no supply valve nor float in the plunger chamber, which, therefore, may be of smaller dimensions, and hence are superior to other closets of this type.

In some plunger closets a special spray arrangement is intended to wash the sides of the plunger and its chamber at each use of the closet, but, while it may be efficient, it tends to complicate the closet. The better closets of this class provide the top of the bowl with an improved flushing rim, or wash the sides of the bowl by an effective fan or water-spreader. In order to provide for an overflow the plunger is sometimes made hollow, and when trapped it is so arranged that the water forming a seal is renewed at each flush. Otherwise it is liable to evaporate and this is especially dangerous with plunger closets that are trapless.

Trapless plunger closets are not safe for same reasons as stated for trapless valve closets.

In some closets an independent overflow is arranged. Most plunger closets are flushed by a valve, worked by a float in the plunger chamber. These valves are not always reliable, especially under varying pressures, and it is much better to flush these closets from a special cistern.

HOPPER CLOSETS.

There are many varieties of hoppers, made in iron or in earthenware. The latter are much preferable, and the former should never be used unless well enameled inside. Among the best hoppers I mention Hellyer's long and short "Artisan" hoppers, Myer's "Niagara" hopper, Demarest's long and short earthen hoppers, Hubers' long and short earthen hoppers, Rhoads' hopper, Ivers' hopper, Harrison's drip tray bowl flushing rim hopper, the Lambeth "Cottage" closet, Smith's "Odorless" hopper, Henderson's Automatic water closet, Maddock's hopper, Moore's "perfectly odorless" sanitary closet, Watson's hopper and others.

Hoppers (Figs. 4, D & E) are sometimes liable to become soiled at the sides of the bowl, and for this reason have not become favorites with many. The hopper lacks the advantage of the pan, valve and plunger closets, in which the excrements drop immediately into a more or less large body of water, and thus carried in suspension by the water, are easily removed from the bowl by tilting the pan or valve, or by lifting the plunger. A good practice is to wet the sides of the hopper before use, and where the hopper is flushed by a special cistern such a device has been arranged to work automatically. The rear part of a hopper should be vertical and straight, so that matters will drop immediately into the water of the trap without touching the sides of the hopper. The inside of hoppers should be very smooth, and for this reason, earthenware is much preferred to enameled iron, because the enamel scales off gradually. In order to have as little surface as possible exposed to fouling the sides of the hopper should be short, which is in some accomplished by having the trap above the floor. The ap-

parent greater cleanliness of the pan, valve or plunger closets is simply a delusion. It is true, the hopper will sometimes have its sides soiled with excrementitious matter, when the supply or the manner of flush is inadequate. But the defect is in sight; it shows itself to the person using or in care of the closet, and it can easily be remedied by proper occasional application of hot water, soap and a scrubbing brush.

Not so with the other closets. The dirty matter may be out of sight, but it often remains hidden in those parts of the closet which are not easily accessible, and therefore never cleaned or inspected, until a leakage occurs, or until some foul odor compels the householder to call for the plumber.

The great merit of hoppers lies in their simplicity and in the total absence of any mechanical parts which, sooner or later, fail to work properly, especially when the closet is carelessly used. Much depends with a hopper closet upon the manner of flush. The practice of turning a stopcock and thus introducing a feeble stream into the hopper, which whirls around its inside, is objectionable. Hopper closets should always be provided with *flushing cisterns* allowing a *bountiful supply* to rush vertically downward through a *large supply pipe* and a *well-shaped flushing rim.*

Rhoads' porcelain seated hopper is a cleanly device for hospitals, schools, factories, railroad depots, public buildings' &c., provided it is well flushed, and only where the apartment can be well heated in winter, as otherwise, the seat being cold, the closet is liable to be improperly used.

Hoppers with wooden rims for a seat, attached to the bowl will answer better than Rhoads' hopper in exposed places, the only objection being the possible absorption of urine through the wood.

WASHOUT CLOSETS.

I have grouped a number of recently invented water closets into this last class which I consider, *in principle*, far superior to any of the other closets for the following reasons: They are mostly made in one single piece of earthenware and are entirely free from any movable parts (see Fig. 4. F). Moreover, the bowl of many closets of this type is shaped in such a manner that its outlet or overflow forms a very efficient water-seal trap, thus obviating the necessity of a trap under the closet. All washout closets have their basin so shaped as to hold a large quantity of water; the advantages of such an arrangement have been already stated. A washout closet is in fact only a modified and improved form of hopper.

In England closets of the "washout" type are preferred of late to other closets, and in this country quite a number of such closets have been introduced. Among closets of the washout type I mention: The "National" side outlet closet, Owen's closet, the Lambeth "Flushout" closet, Carmichael's "Washdown" closet, Woodward's "Washout" closet, Bostel's "Brighton Excelsior" closet, Dodd's Patent closet, Hellyer's "Vortex" closet, the "California" or Smith's "Siphon Jet" closet, the "Dececo" closet, the "Tidal Wave" closet, and others.

Different means are employed with the closets of this class to effect a discharge of the bowl. In many the downward rush of water directed through proper flushing rims so as to concentrate its main force at the outlet of the basin, drives the contents of the bowl into the overflow, and thus into the soil pipe ("Brighton" and "Vortex" closets). In others a jet of water is introduced into the outlet pipe and carries all water from the bowl, partly by the force of the jet, and partly by starting a siphoning action (Smith's "Siphon Jet" closet). In still others a partial vacuum is created by different means in the outlet and a true siphonage established ("Dececo" and "Tidal Wave" closets).

LATRINES.

Latrines and trough water closets are frequently used in public places, schools, railroad stations, factories, hospitals, military barracks, etc. Latrines (Fig. 5) consist of a series of strong stoneware or cast iron porcelain lined pans connected with each other by a suitable vitrified or cast iron pipe at the bottom of the pan or bowl, and forming one piece with it. At the end of the last section a discharge valve is placed, being an upright pipe in which a plunger works, the latter being hollow so as to serve also as an overflow. As the plunger closes the outlet tightly, water is held back in the latrines

to the height of the overflow in the plunger. The plunger or discharge valve is under control of a janitor, who raises this plug as often as found necessary to empty and clean the latrines. The water then rushes out of all the bowls with great force and in great quantity and everything is effectually carried out of the plunger chamber and trap underneath. Moreover, each bowl is provided with a supply pipe to rinse its sides each time the plug is raised. As soon as the plug is dropped, the bowls and connecting pipes fill with water and are, in a few moments, again ready for use. The bowls are generally formed so that no excremental matter can strike their sides; everything drops at once into water and is partly deodorized. The only part which may get foul in time is the plunger chamber, although this is not as likely to occur with latrines as with a single plunger closet.

Trough water closets are constructed in different manners, generally of brickwork with vertical side walls and round bottom, but sometimes of iron, holding a large quantity of water, with the bottom of trough inclined to the end, where the discharge plug is situated, and with a single or double row of seats placed above them. They are somewhat less expensive than latrines, and fulfil, in some cases, a good purpose.

A good substitute for latrines and trough closets may be found in a number of flushing rim all earthen hoppers, such as Rhoads', Hellyers', Demarest's or the Niagara Hopper, with wooden rim attached to the bowl as a seat, each provided with a trap and flushed automatically either by Field's annular siphon tank or McFarland's tilting tank, as often as desired, the operation of emptying and flushing the closet being thus made entirely independent of the carelessness or forgetfulness of the persons using the closet.

GENERAL ARRANGEMENT OF WATER CLOSET APARTMENTS.

In speaking of plumbing fixtures in general I have decidedly condemned the usual manner of encasing fixtures with tight woodwork. While this is objectionable with any kind of plumbing apparatus, it is even more so with water closets. With a tightly boxed-up water closet ventilation is impossible under the seat; the frequent cleaning of the apparatus is neglected, the floor often becomes wetted with urine drippings or water spilled in carelessly using the closet as a receptacle for slops; the filthy liquid soaks into the absorbent floor, which constantly remains damp and emits unpleasant odors into the apartment.

As an abundant supply of water is most essential to the interior of the bowl and closet, so is plenty of light and air indispensable to the outside of the closet. A water closet should stand free on the floor, readily accessible on all sides. The only woodwork necessary is the seat; this should be without a cover and can be hinged and leaned against the rear or side wall, when the closet is not in use. Such an arrangement looks especially neat where the floor is laid in tiles, and if the water closet is entirely of white crockery ware, for instance a long or short flushing rim hopper, or an earthenware wash-out closet.

Col. Geo. E. Waring, Jr., thus describes such an arrangement: a closet, "made of white earthenware, and standing as a white vase in a floor of white tiles, the back and sidewalls being similarly tiled, there being no mechanism of any kind under the seat, is not only most cleanly and attractive in appearance, but entirely open to inspection and ventilation. The seat for this closet is simply a well-finished hardwood board, resting on cleats a little higher than the top of the vase, and hinged so that it may be conveniently turned up, exposing the closet for thorough cleansing, or for use as a urinal or slop hopper. Such closets ought entirely to do away with the use of urinals in private houses, and if, for convenience or to prevent the possibility of baths being improperly used, separate slop sinks are desired, these should be constructed like the hopper closet, the outlet being protected with a movable basket of wire cloth made for the purpose."

The arrangement suggested adds, of course, to the expense of a water closet, but, where white Minton tiles should prove too costly, a plain cement floor, or slate, or else enameled tin may be substituted for them. A tight hardwood

floor is well suitable, and may be covered, if desired, by oilcloth.

Wherever woodwork is used for the sake of better appearance of closets having mechanical parts (plunger closets, valve closets), at least the riser should be arranged with lattice work or a great number of perforated holes to provide ventilation under the seat.

It is desirable to locate water closets near an outer wall, in order to give the apartment ample light, and a window opening on the exterior of the house, for ventilation. Where such an arrangement cannot be secured—and it is seldom possible to do so in American city dwellings—the apartment should have borrowed light and special means for its ventilation should be provided. A dark, unventilated, narrow space for a water closet, opening into a dressing room, or situated off a staircase landing, or even close to sitting rooms, is an abomination. In England water closets are "constructed inside a house with an intermediate vestibule, with a cross-current of air, so as to cut off the air in the house from that in the closet." The rigor of the climate in our Northern States forbids such an arrangement, but in moderate climates it is quite practicable to locate water closet and slop sink apartments in a tower connected to the main building by a passage or hall, which, however, is separated from it by double doors, the hall being efficiently ventilated by two windows on opposite sides. If located in the center of the house such apartments need sometimes artificial lighting by gas, in which case the heat of the gas flame can be utilized to create a constant draft and thus to ventilate the closet apartment by means of tin or galvanized iron pipes, extended—independently for each apartment—through the roof. Fresh air should, in such a case, be supplied to the room, either by blinds in the door, or else by cutting away its lower two or three inches.

Sometimes in order to remove noxious gases generated in using the closet, a special vent pipe is attached to the closet bowl, leading into a constantly heated flue, used for this purpose *only;* or else an upward draft is created in the vent pipe by connecting it with a chamber. in which a gas jet is burning, and the outlet pipe of which enters the flue, or extends up to the roof. Such a venting of the closet bowl is provided, for instance, in the Zane plunger closet, in R. D. O. Smith's "Odorless Hopper Closet," in the "Worcester Hopper," Maddock's "Inodorous" Hopper, Moore's "Sanitary" Water Closet, Huber's hopper, with vent pipe attached to bowl, Watson's hopper, Mott's ventilated hopper, Harrison drip tray bowl hopper, and others.

Sometimes such a ventilation is applied directly under the seat, by using an annular flat zinc tube, provided with a number of openings at the inner edge, and connected to a special flue.

It would be a serious mistake to run such vent pipes into a kitchen flue, and far more so to run them into any other chimney of a building. There is at times a downward draft in these—even in the kitchen flue, the fire of which may go out over night—and thus offensive gases from the closet would be carried into the house. Another reason against such a course is that small vent pipes would soon become obstructed by soot. The best course, where a special flue has not been arranged, is to run the vent pipes along some heated flue up to the roof, and terminate their ends at a point where they are well exposed to the currents of air. These remarks apply also to the vent pipes of containers of pan or valve closets.

It would almost seem superfluous to state that vent pipes from closet bowls should never enter a soil or waste pipe, or a vent pipe from traps. But such cases are not rare, and an instance of such pernicious practice—which should be considered either as criminal carelessness or else as utter stupidity and inability of the mechanic—was related to me only a short while ago.

While speaking of the proposed use of kitchen flues for vent pipes of closet bowls or containers, I might mention the fact that it has repeatedly been proposed to utilize the heat of the kitchen chimney for the ventilation of soil pipes, by running these from above the highest fixtures into such heated flue. Such practice is not permissible under any circumstances whatever, for there are at times downdrafts, which would force soil pipe air into the house. Besides this, it

is well known that bricks absorb gases, and would thus in time become impregnated with sewer gas.

For public places, such as railroad depots, schools, colleges, hotels, etc., where water closets are likely to be used in rapid succession at certain times of the day, a *special ventilation of the apartment* is necessary, even where windows are provided, to remove offensive smells from the use of the closets, which may arise, however well the closets may be trapped and the pipes ventilated. It would lead too far to consider in detail the best means for ventilating such apartments. Suffice it to say, that providing only an exit for the foul gases cannot be regarded as *ventilation*. To preserve the purity of the atmosphere in such apartments it is necessary to introduce a sufficient quantity of pure air, moderately heated in winter time, and to provide an outlet for the foul air. A much disputed question in locating this outlet is whether it should be near the floor or near the ceiling. The former may have advantages from an economical point of view, but from a sanitary point of view, which should only be taken into consideration in the ventilation of such apartments, I should always advise locating the outlet near the ceiling of the room.

No amount of ventilation, however, will keep the air of the apartment pure unless the water closet is frequently and thoroughly washed and scrubbed. Such cleansing is much facilitated with the above suggested arrangement of a water closet.

The following valuable remarks of Mr. Edward S. Philbrick upon this subject so fully express my own views, that I quote them *in extenso:* "The location of plumbing fixtures in dark corners, under stairways and in closed closets is always to be avoided. Such fixtures, even if of the best materials and design, need frequent washing and even scalding to keep them sweet, and the more light and air can be admitted to them, the more likely will the occupant be to enforce such cleanliness. The best authorities in England recommend the location of water closets outside the house walls, in towers or outside appendages. The rigor of our climate forbids such an arrangement in the Northern States, but they can often be so placed near the outer wall of the house as to allow of a window for the direct admission of light and air, *i. e.* in the same apartment. This can be done in all suburban houses without an undue sacrifice of light in the living and sleeping rooms, though city houses can rarely afford anything better than skylight and well light for them. . . . . The water closets on the basement floor are generally the source of much trouble by injudicious location and subsequent neglect. The rareness of the inspection generally given to such fixtures by heads of families renders it all the more needful to place them where they can be readily and easily cleaned and well aired. . . . But however good the apparatus and however well located, nothing will compensate for *neglect* by the occupants of the house. Frequent applications of hot water and soap are just as needful to the surfaces of such fixtures as to the bodies of the persons who use them. Of course the woodwork about them should be so put together as to be readily taken apart without tools by any house-maid, to be periodically cleaned and aired. What is the custom in this respect? Expensive apparatus is often seen so boxed up by screwed and even *nailed* joinery, that the spaces so enclosed are practically inaccessible and soon become abominably foul from spatterings. The less amount of woodwork the better, but by all means have the whole so as to be ready of access without the need of so much as a screwdriver, and let every house-maid be taught the necessity of a regular routine in the cleansing operations, scalding and scouring every surface which has been exposed either to the spattering of urine, or even to the perspiration of the body. It may not be always possible to enforce such discipline, but the less it is enforced, the more important become the items of light, air and simplicity of construction, as aids in the same direction. The latter are generally under the control of the architect, and his mistakes of planning entail a *permanent* and incurable evil, which it is therefore all the more important to avoid. . . . . While every aid should be given to cleanliness by simplifying the apparatus, no amount of

perfection in this respect will avoid the need of constant thought and care on the part of those who use the fixtures, as well as those whose duty it may be to cleanse them. Such perfections of apparatus are but aids, and though not to be ignored by any means, are after all but of little avail if the people who use them are reckless and wanton in their habits. It is difficult enough to keep such apparatus in good order in private houses where not used by any one beyond the supervision of the head of the family, but the trouble increases in a manifold ratio where fixtures are applied in hotels or public places, or in tenements to be used by more than one family."

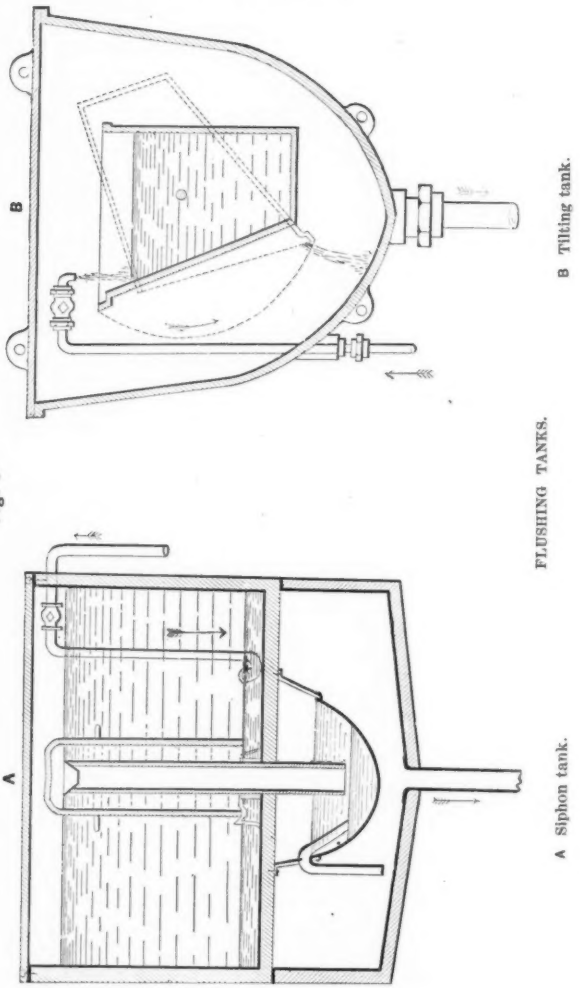


Fig. 6. FLUSHING TANKS.

FLUSHING APPLIANCES.

Flushing tanks should be provided in a system of house drainage, whenever it is impracticable to lay the drain at an inclination which will secure a sufficient cleansing flow. The idea underlying

most of these flushing arrangements is the accumulation of a small flow of water—often merely a driblet—which continuously running, at a sluggish rate, would not be able to remove deposits in the drain. Whenever this water has accumulated to a large volume, the flush tank is automatically emptied and its contents are driven with a sudden rush through the drain. As this may be repeated as often as found necessary, the inside walls of the drain may be kept thoroughly cleansed, and any decomposition of organic matter is thus effectually prevented.

Automatic flush tanks are likewise frequently used for flushing a number of water closets, urinals or slop sinks, and even a single water closet, if in an exposed locality, where the water in the supply pipes would be apt to freeze unless kept constantly running. It has been already stated that such continually running driblets are unable to produce an effective flush, but, by collecting the driblets in a flush tank, discharging automatically, when filled, the desired purpose may easily be accomplished.

There are many varieties of flush tanks, such as Field's siphon tank, McFarland's tilting tank, Shone's flush tank, Maguire's, Rhoads', Hydes', Ivers', Wilson's, Guinier's tanks and others.

Field's flush tank, the invention of the well-known English engineer Rogers Field, has been used with success in this country. One of his tanks has a common siphon, and is started only by a sudden addition of a larger quantity of water. The other tank is provided with an annular siphon, the outer and inner limb being concentric. This tank is started by a small trickling flow. It may be constructed of small size, to flush a row of hopper closets or urinals automatically. Larger tanks are used for flushing house drains and town sewers, and are also adapted for sewage disposal by surface or sub-surface irrigation.

Fig. 6, A, shows a Field's flush tank with annular siphon, the tank being of wood lined with sheet lead. The longer inner limb of siphon reaches into the trapping box suspended underneath, in which the water level is kept about one-sixteenth of an inch below the end of inner limb of siphon by means of the second "auxiliary" siphon. The working of the tank is as follows: As soon as the water from the faucet has filled the tank so that the water rises to the top of the longer (inner) limb of siphon, it commences to overflow, but is guided by a conical-shaped adjutage to drop clear of the sides, and seals the mouth of lower limb. In falling, the water carries air with it, which is thus displaced and driven out at mouth of inner limb in trapping box. A slight vacuum is gradually created in the discharging limb, sufficient to start the siphon, which rapidly empties the tank. As soon as air is admitted through outer (shorter) limb of siphon its action is stopped, all the water in the inner limb drops into the water chamber, and the auxiliary siphon lowers the water line in trapping box about one sixteenth of an inch below the mouth of inner limb. Air enters at this place and completely breaks the siphon; the tank is then ready for another discharge. The stopcock can be regulated to fill the tank more or less rapidly according to option.

McFarland's tank is shown in Fig. 6, B. It works by gravity, and is simply a bucket hung in a cistern, working in brass journals. As soon as filled from a faucet regulated to let the water in slowly or quickly as desired, the bucket tips over and empties the entire contents at once. This tank is well adapted for flushing closets, slopsinks and urinals.

I have endeavored, in these papers, to explain what means and devices should be used, and what rules must be followed, speedily and safely to remove by the water-carriage system all liquid and semi-liquid wastes from habitations. The all-important question of how to dispose of the waste matters of the household in the *safest*, least disagreeable, most efficient and most economical manner has not been referred to.

The discharge of sewage into water-courses or into the sea, its treatment by chemical processes, filtration of sewage, surface and sub-surface irrigation, intermittent downward filtration of sewage, the processes of dry removal, by pail or tubs, earth closets, ash closets, cesspools, privies, vaults, manure pits and kindred subjects, the removal of garbage, kitchen slops, ashes, etc., in other words, "*The Disposal of Household Wastes*," will be made the subject of a future paper.

THE MECHANICAL ENGINEER—HIS WORK AND HIS POLICY.

THE PRESIDENT'S ANNUAL ADDRESS.

Delivered before the American Society of Mechanical Engineers, at the Annual Meeting, November 2, 1882.

By ROBERT H. THURSTON, A.M., C.E., President.

INTRODUCTORY

GENTLEMEN OF THE SOCIETY:—LADIES AND GENTLEMEN:

It is with mingled feelings of pleasure and of regret that I appear before you for the third time to deliver the formal opening address, at the annual meeting of the American Society of Mechanical Engineers.

I have to express, inadequately as I may, my sense of the honor accorded me and my appreciation of that kind feeling and of that confidence which placed me in this chair as your first President, and to-day particularly, my gratification that, after conferring that distinction for another term, both officers and members have so kindly and effectively upheld me in the effort to secure a firm and permanent basis for future usefulness for this Society.

In retiring after two and a-half years of service, I have the proud satisfaction of being able to look back upon an initial period in the history of the Society which is, perhaps, unexampled, and I gladly fall back into the ranks of a body which already numbers 350 members, and which includes in its list nearly every distinguished engineer in the country as well as a large number of the younger and brighter minds now coming forward to do our work, a Society which boasts on its list of honorary members the greatest engineers of Europe.

In the first of my two earlier addresses, I attempted to lay before my audience a concise statement of the character of this organization, the objects proposed to be attained in its formation and by its action, and the principles which I conceived should guide it, as a body, as well as its members individually, in their efforts to further those objects.

In my second annual address, I endeavored to indicate what progress had been made, and what stage had been reached, in the various arts which constitute our department, and to show what direction our steps are now taking and what are the needs of the time so far as they concern the mechanical engineer. I pointed out what seemed to me the more important problems presenting themselves for solution, and stated what were apparently the most promising directions in which to seek results.

I finally called attention to the relation of technical instruction, and of systematic training in the arts to our profession, and urged the supreme importance of making, promptly, the most energetic efforts to inaugurate a general and complete scheme of public and private education.

In this, my third address, I propose to review very briefly the work of the mechanical engineer up to this date, to present a concise summary of what has been accomplished, and to again examine the line of progress with a view to ascertaining more exactly than before in what direction our labors may be most profitably directed in the near future. Nature rarely turns a sharp corner in any of her great movements, and the direction of our progress may be expected, in the immediate future, to be very nearly what it has been in the recent past. Newton's laws hold as well in sociology as in mechanics. Finally, I propose to touch upon those great social problems which concern the engineer even more than our fellow citizens, not simply because he has to deal more directly with them, as an employer and a director of labor and of capital, but, principally, because it is his province, his duty, his privilege, more than that of other men, to study and to solve them, and to inaugurate and carry to position all those great measures to which their solution leads.

MATERIALS.

In the handling of metal, we have still much to learn. The weakness of the

large sections of metal necessarily used in our heavier work still remains a serious evil, and our inability, especially when using steel, to secure the highest tenacity of the metal is a standing reproach to our profession. I have had occasion to test hundreds, yes, thousands, of samples of iron and steel during the last few years and have never yet found a maker able to give equal tenacity in large and small sizes. This difficulty seems particularly serious in dealing with forged iron built up of scrap and with heavy sections of any kind of steel. I find iron carrying 75,000 pounds per square inch in No. 8 wire, 55,000 in inch bars, and falling to 40,000, or even 35,000, in heavy engine-shafts and beam-straps. Steel varies still more seriously. It is to be hoped that, with the more general use of ingot metal, the introduction of hydraulic forging, and of improved methods of heating and handling, so as to avoid the introduction of many small parts in building up large masses, or frequent exposure to high temperatures in the process, this element of cost and danger may, in a measure at least, disappear.

The great testing machine at Watertown Arsenal is constantly at work, under the direction of Colonel Laidley, sometimes for private and sometimes for public benefit, and has already done some extremely valuable work in that important and unexplored field—the investigation of the strength of large sections and parts of structures. Its most valuable work is done intermittently and its usefulness is far less than it should be and would have been had its original purpose been adhered to. There seems no immediate prospect of the resumption of the great work organized in 1875, and planned and commenced by the Government Board.

The petitions of this Society, of the Society of Civil Engineers, of the Institute of Mining Engineers, of the Iron and Steel Association, of the faculties of the leading technical schools and colleges of the United States, and of business men and other private individuals of all classes, with all the influence that they could command, separately or collectively, have been inadequate to secure the restoration of that Board, or the creation of a similar organization, or the resumption of the great work barely planned and begun by the old Board.

This fact is as suggestive of the necessity of a movement on the part of the business men of the country for the purpose of securing some influence in its government, as it is remarkable as illustrating their utter impotence to-day. Meantime, the Ordnance Bureau of the Army has a small appropriation for use in this direction and we shall look with hopeful interest for results.

But "Iron, tough and true, the weapon, the tool and the engine of all civilization," as Theodore Winthrop calls it, is now fairly displaced by its younger rival, "*mild steel*," or more exactly, "ingot" or "homogeneous" iron.

For all shapes that can be rolled this revolution is accomplished and, in forged work of small size, the change is hardly less complete. This is especially true of railroad work, and not only rails, tires and axles, bolts, rivets and boiler plate are becoming common in steel, but piston and connecting rods, all forged parts of the valve gear and minor parts of the engine, are now made in this tougher, stronger and more uniform and reliable metal.

The introduction of the basic process —tardy as it is—by cheapening the stock of the steel maker, and the steadily increas- familiarity of makers and users with the characteristics of the new metal and with the requisites for successful manufacture of demanded grades and better qualities, will undoubtedly, before many years, make its use so general that puddled and forged iron will become almost or quite unknown in our art. The growth of pneumatic steel manufacture in this country during the past ten years has been most remarkable. In 1870 we were making somewhere about 20,000 tons, in 1873 about 160,000 tons, and to-day are turning out one million and three quarter tons; while the price has fallen below that of the finer brands of iron.

A few years ago—even those among us whose hair has hardly begun to grey can remember the time—no engineer except Telford with his proposed cast-iron bridge of 600 feet span, dared present plans of iron truss or arched bridges of 300 feet span; and Roebling was the only engineer bold enough to attempt much greater spans, even with suspension bridges.

To-day, with improved material and

the better knowledge of their quality that comes of intelligent inspection and systematic test, we think little of trusses of .500 feet span or suspension bridges of 1000 feet and more; and it is even proposed to bridge the Forth at its expansion into the Frith with a steel truss bridge a mile long, containing two main spans of 1700 feet each. Not the least remarkable and—to those who pay taxes in New York or Brooklyn to defray the cost of the "East River" bridge—interesting fact in connection with this scheme is that it is expected to cost but about $7.500,000. Who shall say that we are not making progress in this direction at least?

The reduction in cost of the purer, stronger, tougher and more homogeneous grades of so-called "steel" which are to take the place of iron in the near future, and of those which are made by the "open hearth process," especially, will depend principally upon the introduction of the regenerative type of furnace, the great invention of that greatest of metallurgical engineers, our colleague, Siemens, and of the lesser inventors who have followed his lead. With this furnace supplying a means of attaining any desired temperature with a pure mild flame and at a wonderfully low cost of production, we are able to produce the boiler steels and similar metals with an economy that permits competition in this field with even the product of the Bessemer process. With the closed furnace, the attainable temperature is only limited by the temperature of fusion of the materials of the furnace. Could a new and sufficiently refractory furnace material be found, it might possibly be able to compete with the electric furnace of Siemens or with the electric arc with which our colleague Farmer, that Nestor among our electricians, claims long ago to have produced the diamond. The melting of platinum in considerable quantities by Ricketts is now a familiar fact and is an earnest of what may be expected in the more ordinary departments of metallurgy when such enormous temperatures shall be found manageable.

We are not yet absolutely free from annoyance by the presence of air-cells and minor defects in these "ingot-irons" as they are properly called: although such defects have ceased to be dangerous or in any way very serious. Capt. Jones' method of compressing the solidifying ingot by steam pressure, and other devices in imitation of his, are giving us a very homogeneous metal.

Singularly enough, our people, enterprising as we are accustomed to consider ourselves, have not yet made use of the Whitworth system of compression of steel, notwithstanding the fact that its value has, been known so many years and though the wonderful strength, uniformity and toughness conferred by it have made "Whitworth compressed steel" famous throughout the world. Abroad, its use is extending, and guns, screw shafts and other heavy "uses" are often made of it. The venerable inventor informs me that he is preparing plans that will enable even large castings of peculiar shapes, as screw propellors, to be made of this material. Some dozen years ago, studying this method and its results, partly for my own satisfaction and partly to obtain material for a report to the Navy Department, I was greatly impressed with its efficiency as even then developed, and its work has since been wonderfully extended and its value correspondingly increased.

Our systems of inspection and test of materials, of parts and of structures are steadily assuming satisfactory shape and are becoming very generally, almost universally, adopted in all important work, whether public or private, and it will soon be the exception rather than the rule that supplies, material or constructions of whatever kind are purchased without a careful determination of their fitness for their intended purpose.

METHODS.

In my last address, I referred very briefly to the modern *method of manufacturing machinery* in quantity for the market as distinguished from the old system, or lack of system, of making machines. This method compels the adaptation of special tools to the making of special parts of the machines and the appropriation of a certain portion of the establishment to the production of each of these pieces, while the assembling of the parts to make the complete machine takes place in a place set apart for that purpose. But this plan makes it necessary that every individual piece of any one kind shall fit every individual piece of another

kind without expenditure of time and labor in adapting each to the other.

This requirement, in turn, makes it necessary that every piece, and every face and angle, and every hole and every pin in every piece, shall be made precisely of this standard size, without comparison with the part with which it is to be paired, and this last condition compels the construction of gauges giving the exact size to which the workman or the machine must bring each dimension.

Finally: In order that this same system which has introduced such wonderful economy into the gun manufacture, into sewing machine construction and into so many other branches of mechanical business, may become more general, and in order to secure that very important result, a universal standard for guages and for general measurement, we need an acknowledged standard for our whole country, one that shall be an exact representation of the legal standard measure and one which shall be known and acknowledged as such, and as exactly such.

It could hardly be expected that private enterprise would assume the expense and take the risk involved in this last work. Such work has heretofore only been done by governments. Yet among our colleagues are found the men who have had the intelligence, the courage and the determination to accept such risks and to meet such expense, and the men who have the knowledge and the skill needed in doing this great work. I think that the report of our committee on gauges and the paper of our colleague, Mr. Bond, will show that this great task has been accomplished, and we shall find that we are indebted to the Pratt & Whitney Co., to Prof. Rogers and to Mr. Bond for a system of measurement and a foundation system of gauges that will supply our tool makers and other builders with a thoroughly satisfactory basis for exact measurement and for accurate gauging.

It is encouraging to observe that this subject is attracting the attention of men of science, and that so distinguished a body as the British Association for advancement of Science is taking action regarding it.

DESIGN.

Design is to-day conducted systematically and with scientific adaptation of means to ends. The day of the *soi disant* inventor by profession has gone by, and the educated and trained designer has usurped his place. Reuleaux's kinematic synthesis determines the form to be taken by the machine when once the object sought in its construction is plainly defined, and an intelligent application of the laws and data of strength of materials gives its parts their safest and most economical forms and proportions.

The process of invention thus becomes a scientific one, and the inventor himself, instead of blindly groping for, or guessing at, results, is seen intelligently creating new and useful forms, and is now entitled to claim the higher credit and the nobler distinction that we gladly accord to him who performs so high an order of intellectual work and to none more cheerfully than to him who applies the grand Science of Engineering to the production of new forms of mechanism.

As in the Fine Arts, the great painter is known by his success in composition and in form rather than in color, so in our own art, the best work is that which is distinguished by excellence of general design, of arrangement of detail and of proportion, while aimless ornamentation has no place. This characteristic of true art will become more fully illustrated as the scientific method of invention and design gains ground. The most direct and simple adaptation of means to end will always be the object sought by the engineer, and the labors of one of our honorary members, Dr. Reuleaux, have led to the development of a scientific method of discovering those means.

HYDRAULICS.

Let us now look in another direction. The mechaniacal engineer has open to him as his exclusive province one department which is, as yet, only partially developed in practice, although well advanced in theory. I refer to that of *Hydro-mechanics*, and especially the utilization of water power. Although one of the earliest opened by the old Greek engineers, it has been one of the latest developed. Archimides, Ctesibus and Hero were familiar with the principles of fluid pressure; Torricelli, Pascal, Newton and Bernouilli developed the fundamental principles of hydro-dynamics; Du Buat, D'Aubuisson, Prony, Eytelwin and, above

all others, Darcy, supplied experimental data, but it has been reserved for our own generation to apply the knowledge so early acquired to the production of efficient hydraulic engines.

But a few years ago, the vertical water-wheel, as constructed by Fairbairn for moderate and for high falls, and the undershot wheel of Poncelet, were the standard wheels in all countries, notwithstanding their cumbrous size, their slow movement and the great cost involved both in their own construction and in that of their machinery of transmission. Their efficiency was thought high, although rarely exceeding 75 per cent. These wheels have had their day and nothing is likely to occur to save the whole class from ultimate disuse.

The turbine, introduced in an effective form by Fourneyon, a half century ago, and especially in the late forms of Fontaine, Henschel, Jonval, Schiele and others abroad, and by Boyden and his successors in the United States, has become the only water-motor in general use. This small, cheap, quick-running wheel has completely displaced all the older forms, whether overshot, undershot, or breast wheels.

The three principal types—parallel, inward flow and outward flow—are all in use and doing good work.

In Europe, they are all made by good builders, as here; but the tendency seems to be, in the United States at least, to introduce most generally another and peculiarly American type, the inward and downward flow wheel, as illustrated in the wheel built by our fellow member, Risdon.

In efficiency, notwithstanding the comparative neglect of these motors by scientific investigators, there has been a steady and important gain during late years. The improvements which have been *felt out* by makers, working often in the dark—for few builders claim to understand the principles of their art and no two, even, ever agree in their statements of the principles underlying their practice—have resulted in a gradual elevation of standard, until, to-day, a wheel which, under favorable circumstances, cannot exhibit an efficiency of 80 per cent. must drop into the background. I have been asked to certify a trial giving, as claimed, 95 per cent.; but that figure could, I am sure, only be attained by chance, if at all, when all conditions conspired in its favor. But wheels are, I have no doubt, doing work by the day and by the week at 80 per cent. It may be said that Boyden did as well a generation ago. True, but only with large wheels, built as carefully as the chronometer is made, and fitted with polished buckets and diffusers and tested under conditions purposely made the best possible. To-day our builders of turbines give their wheels such exact proportions and take such care in the ordinary work of the foundry that they obtain these high figures from wheels almost direct from the sand.

So far has this change gone that our theory of the turbine as modified by friction requires careful revision. Accepting the older co-efficients for friction and losses of energy, it will probably sometimes be made to appear, from experimental trials, that the wheels of our best makers are a trifle better than perfect. It would seem from figures sent me that friction, in a well formed wheel, becomes partly a means of transfer of energy from water to wheel, and that the loss of efficiency due to that element is much less than has been supposed. In some of the later wheels, losses of energy due to eddies occurring within the flowing mass have been reduced to such an extent as to considerably improve their performance. In the regulation of the turbine, an excellence has been attained that is thoroughly satisfactory in some cases, and the best wheels have been found to give an efficiency at half and at three-quarters gate, nearly equal to the best at full gate. As the efficiency at part gate is often more important than at full gate, it is easily seen that this means a vitally important gain.

MILLING.

A feature of recent progress of general interest, not only to engineers, but to every citizen, is the recent change in *methods of milling.*

It has been found that the cutting action of the millstone is not best adapted to the preparation of a good flour; but that the crushing action of the mortar and pestle or of rolls is much more efficient. "Roller Mills" have been long in use in Europe, and the Hungarian flour, so long noted as the finest in the

world, owes its excellence, not simply to the gluten-charged wheat from which it is made, but largely to the systems of "high-milling" and of cylinder-milling by which its fine grades are produced. The system of "high milling" is a process of gradual crushing and grinding by a succession of operations, each of which gives a finer product than the preceding, while the intervals between them permit the grain to lose the slight heat produced by the slow-running stone. The first step removes the silica coating and the grain is next cracked, then broken up, and finally reduced to fine flour without loss of gluten or other injury, and with less waste than by the familiar system of "low-milling."

By the latest and best method, the grain is gradually reduced to fine flour by passing through a succession of pairs of rolls. In the great "*Walzen-Muhle*" at Pesth, from eighteen to twenty-four pairs are used in making the fine grades of flour. It is this method that is coming into use in our own country, and our hard north-western wheats are made by it into a fine, nutritious flour, rich in gluten, with its grain-cells intact, readily converted into the finest of bread, and of making 150 to 170 pounds of loaf per 100 pounds of flour. The great "Roller-Mill" at St. Paul, Minn., has a capacity of production of 500 barrels per day, and the hard wheat of the north-west supplies it with unexcelled grain.

TRANSPORTATION.

The modern system of collecting the grain raised in all parts of our country, from the Atlantic to the Pacific, from the Southern States to the great grain raising districts of Dakota and Manitoba; the system of storage of the annual product, which now includes 1,600,000,000 bushels of Indian corn and nearly 700,000,000 bushels of wheat, in the great elevators of Chicago, Buffalo, New York and Boston; these later methods of milling; our organization of a meat supply, taking herds of cattle from Texas for the markets of the North and East and for transportation to Europe; our system of packing meats at St. Louis, Cincinnati and Chicago, its carriage in refrigerator cars to the seaboard and in marine refrigerators to European ports; our methods of canning meats as well as vegetables, and thus preserving them from season to season; all these now familiar ways of reducing the cost of living are making further advancement toward a higher civilization easier and more rapid. They supply the first of the two essentials to healthful progress—cheap food and other necessarily consumed necessaries of life—and industrious habits of skilled labor are then to be relied upon in the the production of the permanent forms of wealth.

Our systems of transportation are peculiarly the work of the engineer and are the especial objects of his care. Planned by great engineers like John Stevens, John B. Jervis, and others, of whom we boast as statesmen as well as engineers; built under the direction of Roberts, Welch, McAlpine and other great constructors, they remain in the hands of successors skilled in management and maintenance. All the enormous accumulation of capital in the form of rolling stock is the product of mechanical engineering, and the thousands of trains daily speeding accross the land, each representing in value $30,000 to $150,000 and carrying hundreds of human beings or property worth from $20,000 to a half million of dollars, depend for their safety upon the thoroughness of the builders' work and upon the coolness, skill and judgment of the man who handles throttle, brake and reversing lever—an obvious and forcible reminder of the importance of a profession, one of the humblest and least considered members of which is laden with such enormous responsibility.

ELECTRICITY.

Turning now to the work of the last established branch of our profession, *electrical engineering*, we find ourselves still in the midst of a revolution, the progress of which we are all watching with unusual interest—the displacement of our older methods of supplying light and power by a new system, which, but lately, was but the toy of science and which comes out of the least utilitarian of all the branches of pure physics. Brush has set up his blazing, sun-like, arc-lights in nearly every large city in the world; Edison has spread a network of conductors throughout the most densely settled part of New York City, distributing many thousands of his

clear mellow lights to send their soft, white rays into corners never yet revealed by the feebler yellow light which they displace. It remains to be learned what is to be the cost of the new method of illumination; no figures that I consider wholly reliable have yet been given. It seems sufficiently certain, however, that the arc light is much more economical than gas—the same quantity of light being demanded—for the illumination of streets, public squares and large interiors, while interior illumination by the incandescent lamps is still considerably more costly than any other usual method.

The danger to life and property which come in with the new light are becoming rapidly less, as safe methods of laying and connecting the "mains," of handling the plant and especially more careful and skilful inspection become generally known and practiced. They still remain so great as somewhat to retard the introduction of the electric light.

The secondary batteries of Faure, Planté and others are likely to aid, after a time, in bringing the light into use in many localities in which it would otherwise be impossible to adopt it with satisfactory results and in cheapening the cost of supply. They are still too cumbersome to be of as great value for general purposes as was hoped when they were first invented.

Despite every difficulty and every objection, however, the electric light is steadily and surely coming into a very wide field of application. Its beautiful whiteness, its brilliancy and clearness, its richness in the actinic rays, and therefore its power of revealing every shade of every color, and of producing the chemical changes of photography, its freedom from heat, from vapor and from gaseous poisonous products of combustion, and even its curiously interesting effect in promoting the growth of plants, must all prove qualities of such importance that its extensive introduction, although hardly its exclusive use, must be soon accomplished. As remarked recently by Siemens, gas will long remain the poor man's friend, supplying his rooms with light, and probably his kitchen, ere long, with heat.

Little has yet been done in the electrical transmission of power, except to determine experimentally the efficiency of the system.

I stated last year that the efficiency of the Edison system had been determined, and found to be about 90 per cent. Howell's results have been confirmed by Hopkinson, and by Siemens abroad, and are also checked by reference to Tresca's earlier work. Recently the Messrs. Gibbs have made an extended study and test of the Western machine; and they also find the earlier reported figures for electrical transmission more than confirmed. Taking the probable efficiency of the two machines, forming the system in electrical transmission at 85 per cent. each, we obtain a net efficiency of the system, exclusive of conductor, of above 70 per cent. —this is precisely Tresca's figure, if I remember aright—and, allowing liberally for losses on the line, we may say that 60 per cent. of the power generated may be utilized. But a good engine of large size should give a horse-power with 2 to 2½ pounds of coal per hour, while the small engines which may be displaced by it will demand from 8 to 12 pounds, thus giving an enormous advantage to a system distributing a large aggregate of power to many small users. We shall all look with great interest to the result of actual trial. The electrical railways at Berlin, in Paris, and in Ireland, and Edison's road at Menlo Park, are not likely to remain long uncopied. Our own elevated railroad system offers the best possible field for the utilization of this system; and the often proposed scheme of burning all our fuel at the mine, and transmitting light, heat, and power to our cities along electrical conductors, begins to seem almost a practicable one. We may begin to look once more to thermo-electrical generation as a possible method of transformation at the source of power, as proposed by our distinguished colleague, Farmer, years ago. The fact that while a 4-horse power dynamo deposits about 700 pounds of copper in 24 hours, expending, say 400 pounds of fuel, at least, in usual work, Farmer deposited 400 pounds of copper 20 years ago, nearly, with an expenditure of but 109 pounds of coal burned in his thermo-electric battery, is an important one to be kept in mind in this connection. We may, perhaps, look soon to see this branch of the subject again taken up, and a battery again constructed capable of melting tungsten, and of fusing 8 pounds of platinum in 20 minutes.

Before leaving this subject, it is pleasing to note that in the introduction of new electrical units, our great predecessor, James Watt, is accorded deserved honor beside Ampere, Weber, Ohm, Coulomb, Volta, and Faraday, and that so barbarous a system of nomenclature is made a means of perpetuating the name of so great an engineer, as well as those of such great physicists.

STEAM.

In *steam engine practice*, we are not now advancing rapidly. The introduction of the "drop-cut-off" in 1841, by Sickles; of the now standard type of automatic valve gear in 1849, by Corliss; of the high-speed engine, twelve years later, by Allen and Porter; of the combined advantages of jacketing, superheating and reheating, and the definite acceptance of the compound engine in later years, still constitute the complete history of modern steam engineering; but we are, nevertheless, continually gaining a knowledge of the best methods of handling higher steam; of attaining higher piston speed; of securing greater immunity from cylinder condensation and leakage, and of providing against other causes of waste. We are just beginning to perceive what principles must govern us in the endeavor to secure maximum commercial efficiency, and how economy in that direction is affected by the behavior of steam in the cylinder, and by the mutual relations of all the various expenditures that accompany the use of steam power.

The younger Perkins are still leading in the practice of carrying high steam, and make 400 pounds per square inch—27 atmospheres—is a usual figure while they are experimentally repeating the work of the elder Perkins, and of Dr. Albans, of forty years ago, working steam at 1000 pounds or nearly 70 atmospheres.

Unfortunately, the gain to be anticipated by the use of these enormously increased pressures does not seem likely to be very great, unless some decidedly less wasteful kind of engine can be devised in which to work it. The "Anthracite," with steam at 300 pounds and upwards, was less economical in fuel than the Leila, carrying about one-third that pressure. Emery has stated that a limit seems to be found at about 100 pounds to economical increase of pressure; and Stevens finds a limit due to the geometrical character of the indicator diagram, inside of 250.

One of the most interesting and curious, as well as important, deductions from the rational theory of engine efficiency is the existance of an "absolute limit to economical expansion,"—lying far within the previous accepted limit—due to the fact of increase of cylinder condensation and waste with increase in the ratio of expansion, which places an early limit to the gain due expansion *per se*. It seems possible, if not certain, that this point is often actually reached in ordinary engines within the range of customary practice.

All these facts combined, point to a probability that we have little to hope for in the direction of increased steam engine economy with our standard machinery. Change in the directions that I have already so often indicated are evidently to be our sole reliance—changes limiting loss by cylinder condensation. Probably the surrounding of the working fluid by non-transferring surfaces is our only resource, in addition to, or in substitution for, the now well-understood expedients of high piston speed and superheating. Until that is done, steam jacketing remains a necessary and unsatisfactory method of reducing losses. With a non-conducting cylinder, were it procurable, we might secure very nearly the efficiency of the ideal engine, friction aside, as it would be a "perfect engine," and no natural limit would then exist to increasing economy. Were this accomplished, we might at once reduce the cost of steam power by about one-half in our best engines, and to probably one-fourth or one-fifth the present cost in ordinary machines.

In steam engineering, both physicists and engineers are more than ever attracted to the study of those phenomena which produce the familiar and enormous differences, even in the best practice, between the thermodynamic and the actual efficiencies of engines. The subject lies in that "march-land" territory between science and practice, which few of the profession can explore from both sides, and it has remained less known than it would otherwise be were it either a matter of purely physical science or of practical experience. Fortunately, we are likely soon to see it thoroughly studied. The debate which arose not long since

between Zeuner, the distinguished physicist, as a representative of pure science, and Hirn, the no less distinguished engineer, as an experienced practitioner and skilful experimentalist, in which the differences, to which I have so often called attention, of fifty per cent. or more between the "theoretical" efficiency and the actual performance of the best steam engines, seem for the first time to have been given prominence in Europe, has led to a much closer study of the matter than could possibly otherwise have been brought about.

On this side the Atlantic, the discussion of steam engineering efficiencies has been carried on earnestly, if not always with that knowledge that should precede criticism, and it is to be hoped and anticipated that the engineer may ere long be put in possession of positive facts and real knowledge that may aid him in so designing and so applying this greatest of modern inventions as to attain the *maximum maximorum* of economy.

Ten years ago, nearly, I took occasion to state in a report to the President of the United States on the exhibited machinery of the Vienna exhibition of 1873, printed later with the other reports of the United States Scientific Commission, that "The changes of design recently observed in marine engines, and less strikingly in stationary steam engines, have been compelled by purely mechanical and practical considerations. The increase noted in economy of expenditure of steam and of fuel is, as has been stated, due to increased steam-pressure, greater expansion, and higher piston-speeds, with improved methods of construction and finer workmanship. These several directions of change occur simultaneously, and are all requisite. To secure maximum economy for any given steam-pressure, it is necessary to adopt a certain degree of expansion which gives maximum economy for that pressure under the existing conditions.

"This point of cut-off for maximum efficiency lies nearer the beginning of the stroke as steam-pressure rises. For low pressure a much greater expansion is allowable in condensing than in non-condensing engines; but, as pressure rises, this difference gradually lessens. For example, with steam at 25 pounds by gauge, the best economical results are obtained when expanding about three times in good condensing engines and about one and a half times in non-condensing engines. With steam at 50 pounds, these figures become five and two and a half, respectively; and at 75 pounds, the highest efficiency is secured in condensing engines, cutting off at one-fifth, and in non-condensing engines with cut-off at one-third stroke.

"Owing to the decreasing proportional losses due to back-pressure and to retarding influences, the departure from the economical result indicated for the perfect engine becomes greater and greater, until, at a pressure of between 200 and 250 pounds, the proper point of cut-off becomes about one-sixth or one-seventh, and very nearly the same for both classes of engines, and the increase of efficiency by increase of pressure and greater expansion becomes so slight as to indicate that it is very doubtful whether progress in the direction of higher pressure will be carried beyond this limit."

These conclusions were derived from careful observation of the performance of unjacketted "single cylinder" engines and a comparison of the ratios of expansion of those exhibiting greatest economy. It is interesting to note that later, and probably reliable methods of comparison than were then familiar go far in confirmation of the opinion then expressed. I think that I have been able to prove the existence, as just stated, of an "absolute limit of economical expansion," which, whatever the ratio of steam pressure to back pressure, in all ordinary heat engines probably falls within the range of familiar practice. Advance beyond the best efficiency of to-day in ordinary engines seems likely to be very slow and not at all likely ever to be very great.

Extended experiments will be needed to secure all the facts demanded by the designing engineer and to furnish constants for the approximate theory of efficiency, which only is, as yet, his sole guide. An exact theory is one of those things for which he hopes but which he does not expect soon to see. Some experiments have already been made, but they contribute only the first step. Those made by order of the Navy Department, and principally by Isherwood, and those of Hirn have hitherto been our sole guide, but a new line of more

direct investigation of the laws governing internal, or cylinder, condensation has been inaugurated by Escher of Zurich, and we are able to see a fair prospect of obtaining definite information in this direction.

Escher finds, in the case taken by him that this waste varies nearly as the square root of the period of revolution and of the pressure, and is nearly independent of the back pressure—conclusions which are especially interesting to me as corroborating assumptions, based on general observation and non-experimental practice, made by me previously in developing an empirical system of design.

In steam boiler engineering, the only observable change seems to be the slow but steady gain made in the introduction of water-tube coil boilers and sectional boilers, and in the extension of a rational system of inspection and test while in operation. To-day, the intelligent owner of boilers secures inspection and test, with insurance, by intelligent engineers and responsible underwriters, as invariably as he obtains inspection and insurance of his buildings. Under this system, steam boiler design, construction and management is becoming a distinct art, based upon real knowledge. The system of forced circulation proposed by Trowbridge, and, perhaps, others, seems to me likely to prove useful in the solution of the problem to-day presented.

MARINE ENGINEERING.

In *Naval Architecture and Marine Engineering*, the fruits of the labors of our colleagues are seen in the constantly growing magnitude of our steamships, and in the steadily increasing celerity and safety which mark their unceasing transit from continent to continent.

The "Alaska" makes trip after trip, as regularly as a ferry boat in all but the most trying weather, from Sandy Hook to Queenstown in a week, and has made 18 knots an hour for 24 hours together, and the "Arizona" and the "Servia" are closely rivaling this wonderful performance.

A half dozen years ago I was consulted by an interprising steamship proprietor who desired to learn how far the substitution of steel for iron would aid in the attainment of his aim—the construction of a line of steamers to make 25 miles an hour from shore to shore. A similar project has been lately discussed and it would not be surprising to the well-informed engineer if the plan is carried out within this decade.

Even the ill-famed line between Dover and Calais and other channel routes are benefitting at last by the achievements of the mechanical engineer and the "Invicta," a steamer considerably smaller than the "Pilgrim," has crossed the channel in fair weather in a little over one hour running time—a speed of 18 knots, or 21 miles, an hour—and the "twin" steamer "Calais-Douvres" makes the passage in an hour and a half so steadily that the trying scenes so, unpleasantly remembered by every unfortunate who has crossed on the old boats no longer occur.

This most attractive and difficult of problems presented to the engineer—*to secure a maximum speed, combined with good cabin accommodations and paying cargo capacity*—demands an extent of knowledge and experience, an ingenuity and a degree of practical skill which are demanded by no other task set before the engineer.

My attention has been called to this subject more strongly than ever before, by experiences arising recently in my own practice, and I have been interested in observing how largely the problem resolves itself into one of boiler concentration. The engineering of the machinery is a minor matter; to get a maximum of steam production from a minimum space and weight in the boiler-room and coal-bunker compartment is a vitally important matter. Even where the cargo space is surrendered, it is difficult to secure speed and good cabins in small steamers, and the scheming of a high speed yacht of ample accommodations and of good sea-going qualities is a most perplexing piece of work.

Not the least remarkable work in this department has been done, however. on very small craft. Torpedo-boats require but little weight—carrying displacement—and can be loaded with machinery, and thus the disadvantage of their small size is, partly at least, compensated. They have been given astonishing speeds, but only by forcing boilers tremendously to drive the lightest of engines in the light-

est possible hulls, over, rather than through, the water.

The art of getting high speed is extremely simple in principles but very difficult in practice. It embraces a very few essential requirements:—(1) Lightness of hull; (2) excellence of form; (3) minimum weights carried, whether in cargo, accommodations, fuel or machinery; (4) great impelling power, *i. e.*, for best work, a steel hull; small cargo; few stores; fuel for the least time permitted by ordinary prudence; contracted cabins; small engines driven at the highest attainable speed of piston and by maximum safe steam-pressure, and finally, and perhaps, principally, boilers of small size, carrying high steam, with minimum water space and forced to the very limit of their power. The art of getting large grate area into a contracted and peculiarly-shaped cross-section of hull is one still to be learned.

The torpedo boats of Thorneycroft and Yarrow in England, and of Herreshoff in the United States illustrate the most successful practice of to-day, and their attainment of speeds exceeding twenty miles an hour may be accepted as the most remarkable triumphs of recent mechanical engineering.

With light hulls, weighing but about one-third their displacement, having such fine lines as to occupy but six-tenths the circumscribing cylinder, burning 100 to 150 pounds of fuel on the square foot of grate, carrying 120 pounds of steam, their little engines making 800 to 900 feet of piston speed per minute, at from 500 to 700 revolutions, and weighing but 50 or 60 pounds to the horse-power, this kind of work is locomotive practice of the most radical sort. The secret of success here lies largely in ability to drive the boilers, which are of the locomotive type, forced by powerful fan "blowers," and give a horse-power to each $1\frac{1}{2}$ or 2 square feet of heating surface and from 20 to 30 horse-power to the square foot of grate.

Now that we are using surface condensation exclusively, there is comparatively little difficulty in the introduction of locomotive practice at sea.

But remarkable and important as is this phase of steam engineering, these little craft have revealed in their performance, facts of equal importance in another department. The speeds attained are high, even for large ocean steamers; they are enormously high for such small vessels. It is found that, passing the speeds of 10 or 12 knots, which correspond to high speeds in larger craft, the rate of variation of resistance passes a maximum and then falls from variation as the cube of the speed, or higher, to the $\frac{3}{2}$ power and becomes finally directly proportional to the speed at their highest velocity, thus giving a comparatively economical performance.

Should the same change of law occur with large steamers, maximum railroad speeds at sea may yet prove to be attainable, when, as I have no question will, ere many years be the case, we shall burn at sea a hundred and fifty pounds on the square foot of grate in locomotive or sectional boilers, with steam at 200 or 300 pounds pressure, driving engines at 1000 or 1500 feet piston-speed per minute, turning screws fitted with guide blades as already practiced abroad, and with machinery of steel in steel hulls of less proportional weight than these torpedo-boats.

It is by such changes as these that the mechanical engineer and his colleagues in the trades is gradually revolutionizing the art of war. Before many years, we hope, war will be made so destructive that no nation will dare venture into a naval contest, and the engineer will have then entitled himself to the glorious distinction of being victor over victory itself. He may thus bring about the death of all war, and may give new meaning to Schiller's song:

> "Honor 's won by gun and sabre;
> Honor 's justly due to kings;
> But the dignity of labor
> Still the greatest honor brings."

The screw has become the only instrument of propulsion where it can be used, and can see no reason to suppose that it will not so remain indefinitely; but engineers, who have hitherto been blindly groping to find some new and peculiar form which may possess mysterious principles of efficiency, have now become fully cognizant of the analogy between the screw propeller and the turbine, and are seeking to apply the well-developed theory of the latter to the former.

The value of a system of guide blades and of methods of direction of the cur-

rents approaching and leaving the screw is being determined experimentally, and it is to be hoped that, before long, we may see this instrument rival the better classes of turbine and exhibit an efficiency of 80 per cent. and upward. Thorneycroft has already done good work in this direction.

AERONAUTICS.

It is the reduction of weight of hull and machinery, so remarkably exemplified in recent naval engineering, and the no less remarkable recent improvement in performance that renders it more than possible that we may be on the eve of real advancement in *aeronautics*.

In my last address, I referred to the work done up to that date and endeavored to show how far the researches of Marey, of Pettigrew, of De Laucy and Haughton had developed the experimental science of *aeronautics*, and how far the efforts of Dupuy de Lôme had supplemented the labors of the brothers Montgolfier, of Charles, of Greene, of Flammarion and of Glaisher in actual navigation of the air. I took occasion to indicate what seemed to me to be the promise of the early future and the indications of ultimate success.

Since then, little or nothing has been done, either in research or in aeronautic practice, but Pole has made a study of the problem, and from known data, has determined what we may probably expect to see accomplished when, as may soon occur, the modern methods of locomotive and marine engineering shall be applied to aerial steam navigation by means of balloons. He studies the problem as outlined by Lavoisier, a century ago, 1783, as attacked by Giffard a generation ago, in 1850, and as so nearly solved by him and by Dupuy de Lôme during the Franco-German war. Both attained speeds of between 6 and 7 miles an hour in "*dérigeable*" balloons.

Calculating, from known data, the necessary size of balloons to carry the demanded weights, obtaining by direct reference to known performance the probable resistance of the air-ship, taking the possible least weight of motor at 40 pounds per horse-power, net, 50 pounds gross and 75 pounds including the condenser, and allowing for nearly 20 tons of cargo, Pole finds that a balloon, of spindle form, 100 feet in diameter and 370 feet long may be driven by this torpedo boat style of machinery at the rate of about 30 miles an hour. An air-ship of one half these dimensions would steam 20 miles and one built on one-third scale 12 miles an hour.

These are certainly interesting and remarkable figures; but, as their author remarks, they come fairly and legitimately from existing data. Should the time ever come when the practical difficulties of construction can be fully overcome, it is evident that success in aerial navigation will promptly follow, and we may hope that the time is not far distant when this new product of modern mechanical engineering may become practically useful to the world.

To-day, however, man with all his vaunted intelligence and with all his wonderful powers, is in this field beaten by every bird that flies and even by the so minute an insect as the gnat, which is only to be seen when disporting in the sunbeams.

Elmirus and Joseph Degnan have, as yet, no followers known to fame, and stand beside Bushnell and Fulton who inaugurated submarine navigation, but yet are without successors.

CAPITAL AND LABOR.

In singular and discreditable contrast with all this gain in recent and current practice in engineering stands one feature of our work which has more importance to us and to the world, and which has a more direct and controlling influence upon the material prosperity and the happiness of the nation than any modern invention or than any discovery in science. I refer to the *relations of employers to the working classes* and to the mutual interests of labor and capital. It is from us, if from any body of men, that the world should expect a complete and thorough satisfactory practical solution of the so-called "labor problem." More is expected of us than even of our legislators. And how little has been accomplished!

Yet it would seem that the principles involved are simple and that the practical difficulties should be readily overcome. The right of every man to buy or sell labor wherever and whenever he may choose and wherever and whenever he

can make the best bargain is one of those rights which are natural and inalienable. The right of every man to engage in any occupation, or to enter into any department of honest industry, to train his children for any productive occupation, or to secure for them any kind of employment, is an equally natural and inalienable right. The privilege of accumulating property to any extent and by any honorable and legitimate means, is also naturally and legally accorded to every citizen. It would seem obvious that one of the first claims of the citizen upon the State is that he shall be absolutely assured of these as constitutional rights. Any infraction of such rights and any attempted contravention of such privileges, whether by individuals, by legally constituted corporations or by associations unknown to the law, should be promptly dealt with, and so severely, whether the culprit be of high or low degree, that the offence shall not be likely to be repeated.

No legislation should be permitted that shall injuriously affect any morally unobjectionable industrial enterprise or that shall impede any fair commercial operation, whether in the exchange of commodities or the transfer and use of capital. Only such a tariff system, even, can be safely permitted as shall encourage fairly the growth of such new industries as are adapted to our climate, soil, and other natural conditions.

The prosperity of a people is dependent upon their industry, integrity, skill and enterprise, as well as upon the natural resources of the country, and the object of every government and of all legislation is to protect the people in their right to a fair reward for their industry, skill and enterprise, to promote that mutual confidence that comes of real business trustworthiness, and to develop the natural resources and advantages of the State. The protection of the individual in his right to learn, to labor and to traffic; the encouragement of natural enterprises, the diversification of industries, the promotion of the ability of the people to produce valuable materials and all kinds of products of the higher classes of skilled industry, the encouragement of invention and the making of the nation independent of all possible rivals or enemies in the production of whatever is necessary to the existence or the comfort of the people, are all perfectly proper objects of legislation. No legislation which neglects or opposes these objects can aid us. No legislation can serve the nation which aims to help either the employer or the employé, either the capitalist or the laborer, *alone*. No industry can permanently succeed which does not make both classes prosperous, and no statecraft is deserving the name which does not aim at the support of both. If either is discouraged and driven out of the field, business ceases and suffering results.

Again, force and intimidation have no place in matters of business. All legitimate operations, whether in commerce or manufactures, are the result of mutual agreement for mutual advantage. Strikes and lockouts, as well as their usual, but shameful, concomitants, intimidation and violence, are wholly out of place in our industrial system and should be repressed by every legal means, as absolutely opposed to the spirit of civilization and to the letter of our Declaration of Independence. The simplest principles of political economy and social ethics cover this matter fully. Labor, like any other salable possession, will have a value determined accurately by the great law of supply and demand, and the interruption of traffic in labor, and at the same time the compulsory interruption of production, in the end only result in serious injury to both parties to the controversy and to the whole country as well.

The introduction of a general system of arbitrament, the formations of unions between associated employers and of associated employes, the diversion of the trades unions into their legitimate channels of usefulness will ultimately, we may be sure, effectually reform all the existing abuses in this direction. Already workingmen are learning that strikes almost invariably cost far more than they gain; capitalists are beginning to understand that their pecuniary interest, as well as ordinary humanity, dictate careful consideration of, and respect for the rights and interests of labor and, ere long, when employers sustain labor exchanges in all our great cities and when trades unions confine themselves to benevolent enterprises and the assistance of those members who desire to reach better paying fields of labor, we may ex-

pect to see every industry settle down to a steady, unintermitted routine which will give maximum production while every worker will have uninterrupted employment at rates of pay which will be the maximum value of the labor sold. If every boy were made familiar with Nordhoff and every man with Adam Smith and Spencer and Stuart Mill, we might hope that it would become universally understood that highest prosperity can only come when business can proceed without interruption by strikes, lockouts, or unintelligent legislation. A perusal of Eaton's excellent report on Civil Service suggests the thought that such a system is as desirable in every industrial organization as it is in the public service.

Grimm, in his life of Michael Angelo, says that three powers rule every state, and they are variously classed as "Money, Mind, Authority," as "Citizenship, Science, Nobility," or "Energy, Genius, Birth." I would say, in each individual, "Talent, Power and Character," or "Genius, Strength, Integrity" are ruling powers, but that we are yet to see them rule the State. That the time is coming we may, I am sure, both hope and believe, but a great change must first take place.

We need a Junius to write, a Burke to speak, and a Chatham to illustrate a real reform.

The elements of social economy are yet to become known to our people; the most obvious principles of statesmanship are yet to be learned by our legislators, and we have still to look forward to a time when our men of business and our working people shall be fairly and respectfully considered by those who direct public policy. Before the needed reform can be made productive of general good, we must return to the original theory of our government—that all government has for its object simply the preservation of the rights of the people in their pursuit of the best life, the highest liberty and the purest happiness; that it should guarantee to all, of whatever race, creed, powers or sex, a common right to live, to learn, to labor and to acquire and hold property, with absolute freedom of thought, speech and right-doing.

To attain all that we desire and to secure highest efficiency in our political and social system, we must have a business man's and a working man's government. The professional politician and the machine system must become extinct. Our public policy and our law making must be made subservient to industrial interests. The people, and not self-seeking ward politicians, must frame the code and direct the expenditure of public funds.

SYSTEMATIC PROMOTION OF INDUSTRIES.

And these considerations bring up the question:—How can so desirable a change in politics and in industry be brought about?

There is but one answer: By systematic and carefully planned encouragement of all industries, a system that shall illustrate those methods which are the true object of all government, a system, also, which shall supply means by which full advantage may be taken of all those opportunities, which present themselves to every citizen of the United States.

Such bodies as this must aid our legislative assemblies in developing a *scheme of industrial organization*, that shall exhibit highest possible efficiency—one that will prepare the children and youth of the country to enter upon lives of maximum usefulness, and to do the work that may be given them to do with ease and comfort, while, at the same time aiding them to attain health, happiness and content, even if not independence and wealth.

It is easy to see what must be the leading features of such a system. Since the prosperity of the State and of the people depends upon the integrity, the skill and the industry of its citizens; it is evident that the cultivation of good morals, a keen sense of right and a high sense of honor are primary requisities; that the instruction and training of every youth in the art for which he is best fitted is essential; that a fair general education is equally necessary to afford sources of intellectual pleasure; that a reduction of the hours of labor to a minimum healthful length must give opportunity for continual self-improvement and for healthful recreation.

It is obvious that we must find ways of encouragement of those industries, the success of which are best assured by our climate, our soil, our topography, and by our social and political conditions. We must take steps to secure by systematic legislation and by every other

proper means a diversification of skilled industries and such a relative distribution of agricultural and manufacturing population as shall bring to each all the necessaries and comforts of life at minimum cost.

It is our task to study the soils, climates and natural resources of this wide land of ours, to learn what products of the soil and what manufactured articles can be made to give the best return for time and money invested, and then to systematically develope by public policy and private enterprise, every such industry, securing the highest skill, the most reliable labor and the finest artistic talent by conscientiously cultivating them. Skilled labor has a steadier market and makes a steadier market than unskilled, and our effort should evidently be to lead the world in its development, cultivating all profitable manufactures which demand greatest skill and highest talent; encouraging a varied industry; making the expenditure of capital and labor on transportation and on coarse work a minimum, and making the most of every pound of raw material brought into our market before putting it on sale again. Any system of encouragement of domestic industries that may be adopted must evidently include a practical and fruitful plan of careful education and of regular training in the trades and arts capable of successful growth among us, making our people the equals, and, if possible, the superiors of their competitors in other countries, in intelligence, skill, knowledge and enterprise. It must introduce new industries and diversify old ones. It must teach the child, train the youth and protect the man from excessive outside rivalry.

Only when our whole population has become as intelligent, as skillful and as well informed in every branch of every industry, existing or arising in the State, as any other people can possibly be, only then, may we rely safely upon profiting fully by all those advantages due to our natural position and resources.

Such a plan must be carefully considered by the sages of the community, and only adopted after deliberate study and thoughtful consideration. But a few general principles are readily discoverable. A half dozen years ago, at the request of a commission appointed by the State of New Jersey, of which commission I had the honor to be appointed secretary, I prepared a general outline of such a scheme as that which now interests us, and based it upon the following "platform":

Such a plan, to be satisfactorily complete, must comprehend:

A common school system of general education, which shall give all young children tuition in the three studies which are the foundation of all education, and which shall be administered under compulsory law, as now generally adopted by the best educated nations and States on both sides the Atlantic.

A system of special adaptation of this primary instruction to the needs of children who are to become skilled artisans, or who are to become unskilled laborers, in departments which offer opportunities for their advancement, when their intelligence and skill prove their fitness for such promotion, to the position of skilled artisans. Such a system would lead to the adoption of reading, writing and spelling books, in which the terms peculiar to the trades, the methods of operation and the technics of the industrial arts should be given prominence, to the exclusion, if necessary, of words, phrases and reading matter of less essential importance to them.

A system of trade schools, in which general and special instruction should be given to pupils preparing to enter the several leading industries, and in which the principles underlying each industry, as well as the actual and essential manipulations, should be illustrated and taught by practical exercises until the pupil is given a good knowledge of them and more skill in conducting them. This series should include schools of carpentry, stone cutting, blacksmithing, etc., etc., weaving schools, schools of bleaching and dyeing, schools of agriculture, etc., etc.

At least one polytechnic school in every State in the Union, in which the sciences should be taught and their applications in the arts indicated and illustrated by laboratory work. In this school, the aim should be to give a certain number of students a thoroughly scientific education and training, preparing them to make use of all new discoveries and inventions in science and

art, and thus to keep themselves in the front rank.

A system of direct encouragement of existing established industries by every legal and proper means, as by the encouragement of improvement in our system of transportation, the relief of important undeveloped industries from State and municipal taxes, and even, in exceptional cases, by subsidy. It is evident that such methods of encouragement must be adopted very circumspectly and with exceedingly great caution, lest serious abuses arise.

This system should comprehend, perhaps, a Bureau of Statistics, authorized, under the law creating it, to collect statistics and information relating to all departments of industry established, or capable of being established, in the State.

I would place, as the head of this whole system of aid and encouragement of all legitimate industries, a great central University of the Useful Arts and Sciences which should be the directing member of the whole organization, furnishing higher instruction to the son of every citizen who can find his way to it, supplying the polytechnic schools and colleges with the most learned and talented instructors, aiding by scientific investigations the development of every industry, and serving as an attractive nucleus around which should gather the great men of every department to serve the State in that highest of employments, the instruction and training of our youth, and by giving counsel to legislators and executive officers of every department of the Government, in concert with our already established National Academy of Sciences.

Washington urged the creation of a National University, a primary object of which should be the education of youth in the Science of Government. Jefferson, also, urged the foundation of "a National Establishment for Education," and John Stuart Mill has said, "National institutions should place all things that are connected with themselves before the mind of the citizen in the light in which it is for his good that he should regard them."

Experience at home and abroad shows that systematically conducted schools of art, and trade schools, are vastly more efficient and economical in the education and training of youth than the best managed mill or workshop. Every operation can there be taught, and the learner made perfectly familiar with each detail, without causing the inconvenience and pecuniary loss which are sure to come with such an attempt in the shop.

Very much such a complete system of technical science of instruction and of industrial education has been incorporated into the continental educational structure, and there places before every child in the land the opportunity of giving such time as the social position and pecuniary circumstances of its parents enable them to allow to devote to the study of just those branches which are to it of most vital importance, and to acquire a systematic knowledge of the pursuit which surrounding conditions or its own predi lections may lead it to follow through life, and to attain as thorough a knowledge and as high a degree of skill as that time, most efficiently disposed, can possibly be made to give him. There is here no waste of the few months, or years of, to him, most precious time, which the son or the daughter of the humblest artisan can spare for the acquisition of a limited education. Every moment is made to yield the most that can be made by its disposition in the most thoughtfully devised way that the most accomplished artisans and the most learned scholars, mutually advising each other, can suggest. One day, in such schools as those here described, is of more value to the youthful worker than a week in the older schools, or than a month in the workshop or the mill. Thus, while the fact is recognized that a general and a liberal education is desirable for every citizen, the no less undeniable fact is also recognized that few citizens can give the time to, or afford the expense of, a symmetrical general course, and that the interests of the individual and of the State unite in dictating the provision of such systems and means of industrial education and training as are now actually provided.

It is in consequence of the adoption of an intelligent and extensive system of the character of that which I would propose for our own country that it has become now generally admitted that Germany is the best educated nation of the civilized world. (There is danger

that the United States may, with reason, be reckoned the worst.) Germany is gaining a better industrial position daily; our own country is retrograding in all that tends to give manufacturing pre-eminence, except in the ingenuity, skill and enterprise of its people; and the one great, the vital, need of our people is a complete, efficient and directly applicable system of technical instruction and of industrial training, if they are to avoid the successful and impoverishing competition of nations which have already been given that advantage by their statesmen and educators a generation earlier. The question whether this comparison shall remain as startling and as discreditable to the people of the United States in future years as it is to-day, is to be determined by the ability of our people to understand and appreciate the importance of this subject, by the interest which the more intelligent classes may take in the matter, and upon the amount of influence which thinking citizens and educated men and the real statesmen among our legislators may have upon the policy and the action of the general and the State Governments. The promptness and energy which we may display in an effort to place ourselves in a creditable position among educated nations, will be the truest gauge of the character of the people of the United States. Judged by her progress in this direction, Europe is far in advance of us in the most essential elements of modern civilization.

There, instead of standing aloof from each other, and instead of forgetting, as is too frequentlly the case in our own country, those great facts and those imperative duties which every statesman does, and which every citizen should, recognize, the governing and the educated classes, have worked together for the common good, and have given Germany, especially, a vantage-ground in the universal struggle for existence and wealth which is likely, in the future, to enable that country for many years steadily to gain upon all competitors.

Our own work, thus far, has been desultory, sometimes ill directed, and rarely thorough or systematic. Our "technical schools," so-called, are often modified trade schools, and our few trade schools frequently aspire to the position of polytechnic schools, and both classes are confounded in the minds of very many, even in the profession, and their work is seldom done with that maximum efficiency which can only come of intelligent organization and definite aims and fields of work. So it happens that while the system of general primary education is more widely spread and more effective than in any country in the world, and while we have a larger number of schools, in proportion to population, than perhaps any other country, we are nearly destitute of trade schools, and have extremely inadequate provisions for industrial education of any kind and for any class of our people.

This system of preparation of every citizen for useful work and a prosperous life being adopted, there remains to be considered what can be done to aid the great industries into the channels of which all this skill and training in the arts and applied sciences is to be directed.

GENERAL CONCLUSIONS.

A complete working system of preparation being inaugurated, all is done that can be done for the individual in the endeavor to place him on a fair vantage ground in the struggle for survival which is going on throughout the world. Beyond this, he must trust principally to his own intelligence, skill, industry and frugality for success in the effort to secure the necessaries and comforts of life, and to acquire luxuries, a comfortable independence in old age, and the means of starting his children on a higher level than that which he has himself reached.

A plan for the encouragement of our industries and to secure permanent prosperity must include a general policy of legislation which shall aid the capitalist to safely invest his funds in manufacturing enterprises, or in agriculture, shall assist the working man and the working woman to find remunerative and permanent employment, shall protect everyone in the right to sell his capital or his labor at the best market value, wherever and whenever he chooses to offer it, and to give and to take in fair bargains without let or hindrance.

Such a policy must sustain every good workman in the effort to secure a good price for his labor and every employer against every attempt to compel him to pay good wages for bad work or to sur-

render the control of his business or his property to any other man.

Legislation must be general and must so far as possible, avoid either direct or indirect interference with the natural currents of trade. It must facilitate, not obstruct, natural industrial movements. The welfare of the people, and not of any class, rich or poor, must be studied.

The fruit of such a system as I have outlined will be fully seen only when all our labor is skilled and intelligent; when all our directors of labor are familiar with the science of their art, and when our men of science are all men applying science.

Renan, in his autobiography, expresses his conviction that succeeding generations will be taught principally natural sciences, for the reason that the truths learned in their study have more import ance to mankind and have a deeper inter est than the facts of history or the accumulated stores of general literature.

Men of Science and Men of Art, too, are becoming known and acknowledged as of most importance to mankind and as the principal reliance of the race in its terrible struggle against poverty, disease, misery and death. The influence and the power of men who devote themselves to the study of the phenomena of nature, and of those who make useful application of a knowledge of nature's facts, laws and forces, must inevitably and continually increase so long as civilization shall continue to advance.

The world will finally reward most nobly those who thus most nobly strive to forward its highest aims.

THE MARINE BOILER.*

From the "London Times."

Mr. Shock, of the United States Navy, is the author of a treatise on steam boilers, which, for comprehensiveness and thoroughness of treatment, and fullness of illustration, may serve as a model for English engineers. It is at once theoretical and practical. Beginning with chapters on the nature, process, temperature, and products of combustion, and upon the law of transmission of heat and evaporation, the author subsequently directs the attention of the reader to a consideration of the materials of which boilers are made, and of the principles which should determine their design, construction, and management. His plan of treatment is thus systematic and progressive. The young engineer is taught not only what constitutes an efficient steam generator, but why efficiency results from the observance of certain conditions of form, and the proportional ratios of heating surfaces to water space and steam pressure. There are also chapters on the deterioration of boilers, and upon boiler explosions.

It is an axiom in mechanics that the strength of a structure is determined by the strength of its weakest part. Now, there can be little question that the weakest part of a man-of-war or an ocean steamer is its steam-generating apparatus. The engines propel the ship, but they can only transfer to the ship in the form of motion the power which they derive from the boilers in the form of pressure. The mere circumstance that Mr. Shock has written a voluminous quarto treatise on the construction and management of steam boilers, illustrated with upwards of 30 pages of plates, is enough to prove that much is to be said upon the subject, and that the stage of finality has not yet been attained. For, while the boiler is a source of power, it is also a source of weakness and of constant anxiety and watchfulness on board ships. Its complicated ramifications, and the difficulty which it offers to inspection render it, even under uniform and normal conditions, very liable to get out of repair. In a man-of-war, however, where it is subjected to continual fluctuations of pressure—sometimes being forced until the steam lifts the safety-valves, and at other times only pushed a little over the atmospheric pressure—it is still more

* "Steam Boilers: Their Design, Construction, and Management." By William H. Shock, Engineer-in-Chief United States Navy. New York: D. Van Nostrand.

liable to wear itself out, and exhibit unexpected infirmities long before the period of old age is reached. It is the chief element of trouble and danger against which the marine engineer has to guard; and in all naval services, and certainly in ours, the orders and regulations which are issued for the management and preservation of boilers are more numerous and stringent than those issued with reference to any of the other manifold equipments of a ship of war. The boiler may explode and produce other explosions. In the case of the Thunderer, the explosion was caused by the closing of the stop-valve and the simultaneous jamming of the safety-valves. An explosion may also occur through inattention to the water gauges, to internal incrustation, or to inherent weakness. But accidents of this kind, to whatever secondary causes they may be due, are, as a rule, the result o carelessness on the part of the enginef room staff. Boiler explosions may be practically regarded as preventible. But ship's boilers are sadly liable to get out of order by the persistent use of the blast, by the formation of saline deposits, by wear and tear, by the intrusion of fatty matter from the warm well, by pitting, by the introduction of moist air, and from other causes of deterioration for which the Admiralty Boiler Committee have lately proposed various remedies. In the best of circumstances the life of a marine boiler in constant use cannot be relied upon to extend over more than from eight to ten years. Besides the above sources of inefficiency, the boilers of a ship occasionally fail from insufficiency of steam space and draught, from priming, or "foaming," as Mr. Shock prefers to call it, from the coating of the tubes with soot, and from a simple want of power to meet the demands of the engines. On the whole, the marine boiler is a costly and at times an exceedingly troublesome charge on board ship.

Mr. Shock does not confine himself to the construction and management of ships' boilers alone, but discusses the whole complicated subject of steam generators. He devotes, however, the bulk of his work to the consideration of the marine boiler, and it must always tax the ingenuity of the practical engineer more than any other. As the writer observes, the designing of a boiler of this sort, and more particularly for service in the Navy, involves the fulfilment of conditions, which are, to some extent, antagonistic. Hence, compromises have to be accepted, and many advantages with regard to economic and potential efficiency have to be sacrificed to other essential requirements. In the matter of tubes, for example, the efficiency of their action as heating surfaces, has been subordinated to the necessity of increasing the draught. In an ordinary boiler the principal conditions to be satisfied in the design are that it must be able to provide the necessary amount of power, that its parts must be arranged with regard to durability and economic efficiency, and that every portion must possess the required strength. Boiler efficiency is commonly defined to be the proportion borne by the heat transmitted to the total quantity of heat that would be yielded by the complete combustion of the fuel. The efficiency of the heating surface, on the other hand, is the proportion borne by the quantity of heat transmitted to the water in the boiler to that available for transmission. If, therefore, the combustion could be made perfect, the efficiency of the heating surface would be the efficiency of the boiler. As this, however, is not practicable, very elaborate measures are necessary to secure the largest amount of efficiency. Thus the length and width of the firegrate must be such as will permit of the proper management of the fire and of the cleaning of the back and front corners; the ashpit must admit a sufficient quantity of air, moving at a low velocity to every part of the grate; the furnace must afford ample space for the gases to mingle thoroughly and allow of the proper consumption of the fuel; the combustion chamber must be spacious enough to permit the gases room and time to complete their combustion before entering the tubes; the heating surfaces require to be arranged in such a way as to facilitate the escape of steam from them as soon as formed; while the water spaces must not only be strongly stayed, but must be designed to admit of the free circulation of the water and of the rapid formation of steam on the furnace crown.

In the marine boiler, however, certain

limitations, which seriously fetter the hands of the engineer, must be taken into account. The space available on board is always circumscribed, and sometimes unnecessarily so, while the weight of the boiler and its attachments and fittings must be kept within the lowest limits compatible with safety. There is also the important difference that salt water must be used, though the quantity, owing to the introduction of surface condensers, has been reduced to a *minimum*. In a man-of-war, where it is especially important that all parts of the machinery and boilers should be placed as low as possible, it is generally stipulated, in spite of the protection which is now afforded by armor and wing bunkers, that no part connected with the steam space of the boilers shall protrude above the water-line. Boilers are necessarily, therefore, placed in the narrowest parts of a ship, with the result that they are greatly cramped and confined. Hence defective combustion, in consequence of the variable draught of the furnaces and the difficulties of stoking, ensues. When ships are entirely denuded of masts and are made to depend entirely upon steam propulsion, more attention will probably be given to the effective disposal of boilers. Various methods have been adopted with a view of improving the steam arrangements. Generally speaking, the rule was to crowd the boilers of a man-of-war into a single stokehold forward of the engines; but in the Mercury and Iris class they are located in two stokeholds, separated from each other and the engine-room by thwartship bulkheads. It was also the custom to place their ends close against the sides of the ship and to stoke from the center; but in modern armor-clads the system has been introduced of dividing the boiler-room by a longitudinal water-tight bulkhead and stoking from the wings. This plan secures greater comfort for the stokers and affords additional security for the ship. In the Inflexible double-ended boilers have been adopted, but they seem to have dropped into their places without any other purpose than that of filling up a little spare room.

The types of marine boilers are very numerous, apart altogether from the grand distinctions of low and high pressure. Some have the tubes vertical and others horizontal; some are fitted with water tubes while in others the tubes form the heating surfaces. Steel locomotive boilers, similar to those carried by torpedo boats, have been lately introduced into the Polyphemus for the sake of economy as regards space, combined with extraordinary working pressures. The result, so far, however, has not been attended with complete success. The boilers which are generally used in Her Majesty's ships are of the horizontal tubular type, with regard to which the area of the firegrate is the principal factor in determining the space to be occupied by them in the length and breadth of a vessel. The power of a boiler is measured by the weight of steam which it can generate in a unit of time, and the working pressure varies from 30 lbs. for simple engines, 60 lbs. for compound engines, and 120 lbs. and upwards on the square inch in the new steel boilers which have been provided for engines working at great rates of expansion. In low-pressure boilers of the best kind. driven at full power, about 30 lbs. of coal is burnt per hour and 10 indicated horse-powers developed per square foot of firegrate, while in high-pressure boilers the amount of coal consumed is 21 lbs. and the power developed 8.5 per square foot of grate. These are the *data* adopted by Mr. Sennett in his work on the marine steam engine; but Mr. Shock thinks it may be assumed for general purposes that engines consume from 20 lbs. to 30 lbs. of steam per indicated horse-power per hour, the latter quantity being consumed by engines using saturated steam of about 35 lbs. pressure above the atmosphere, with a moderate rate of expansion, the cylinders having no steam-jacket. The former quantity is required for the best types of engines using dry steam of from 60 lbs. to 80 lbs. pressure and working at a high rate of expansion, the cylinders being steam-jacketed. A marine boiler of ordinary kind and proportions, using natural draught, produces under these conditions, with anthracite coal, from 3.5 to 5.5 indicated horse-powers per square foot of grate, while with a free-burning, semi-bituminous coal, it produces from 4.5 to 7.5 indicated horse-powers per square foot.

Mr. Shock writes very cautiously and vaguely on the subject of forced draught,

which is at present interesting English engineers, and the advantages of which are so assured, under certain conditions, that it has been introduced into the Polyphemus and the cruisers of the Leander class, and is stipulated for in the specifications for the Benbow and the Camperdown, which are about to be laid down. It is clear that the author has had no experience with reference to its use. "With forced draught," he observes, "as many as 10 indicated horse-powers per square foot of grate have been developed by several large English naval vessels of recent construction, during their full-power trials for six consecutive hours at sea, by using from 25 lbs. to 30 lbs. of carefully-selected free-burning coal per square foot of grate per hour." But it is clear that Mr. Shock here refers to the use of the steam blast, a method of stimulating a sluggish draught which the Admiralty do not approve and which they desire shall be discontinued as much as possible at official trials. In America many experiments have been made with the object of determining the benefit of facilitating combustion by forcing air directly under the grates by means of fans. This method of increasing draught is said to be very economical; but, as the blast in this case must be delivered with air-tight ashpit doors, the ventilation of the stokehold is almost wholly destroyed, and the stokers find the heat and dust insupportable. In the system of forced draught which is now being gradually and somewhat timidly introduced into the English navy the air is delivered directly into the boiler-room, which is enclosed by air-tight bulkheads and decks, and has no outlet for the air, except through the grates. By this method an increased barometric pressure is produced. The boilers are worked with open ashpits, and the ventilation of the boiler room is as perfect as with the natural draught. There is. no doubt, a certain amount of loss from leakage, but this is scarcely appreciable, while in closed ironclads, in which natural draught must be always imperfect and variable, the advantages are great and important. As has been already stated in these columns, with the use of forced draught there would not only be an abundance of air delivered into the stokehold under all conditions of wind and weather, but the amount would be uniform and produce a uniform head of steam. The amount of pressure, also, would be adjustable to the varying circumstances of the moment. What, however, is particularly desiderated in a man-of-war is the combination of alertness with powers of offence and defence. It is of supreme importance that it should possess what is termed "nimbleness,"—that is, a power in critical emergencies of putting on a great spurt on short notice; adding a knot or two to the regular full speed for a brief period, or as long as a modern naval action is likely to last. For this purpose forced combustion must be depended upon. Superheaters are another subject on which Mr. Shock writes with considerable vagueness. In the American navy the practice of using superheated steam appears to be general, but in our own it has been well-nigh discarded. Under certain conditions it tends to increase the dynamic efficiency of the engine and produces economy in the consumption of fuel; but much depends upon the temperature of the saturated steam and upon the rates of expansion due to the cut-off. For general purposes the gain is inconsiderable, and is counterbalanced by the additional wear and tear, the scoring of the cylinder which it causes, the greater friction of the piston, and the tighter packing which is necessary to prevent waste. Superheaters are accordingly getting out of favor even when applied to low pressure boilers; while to the high pressure types they are seldom fitted, because the greatest temperature of steam that can be safely used in ordinary marine engines appears to be about 340 deg. to 350 deg. Fahrenheit, so that there is very little margin for superheating steam of 60 lbs. pressure and upwards.

The specification for the construction of boilers for the English navy are less detailed than for those of the American service. They are, nevertheless, sufficiently comprehensive and stringent to secure good material and workmanship. All plates (with the exception of Low Moor, Bowling, or Farnley plates, which are not tested), must be capable of withstanding a tensile strain of 21 tons per square inch lengthwise and of 18 tons crosswise, and a hot forge test of being bent 125 deg. lengthwise of the grain and 100

deg. across. They are also required to pass a crucial cold forge test. Angle and other irons and rivets used in their construction must be also subjected to similar ordeals. Each of the tubes are to be proved by water pressure separately up to 300 lbs. per square inch; and it is further demanded that the *maximum* strain on the stays at the working pressure shall not exceed 5,000 lb. per square inch of section at the bottom of the thread. After the boiler has been constructed according to the specifications, it is required to be tested by hydraulic pressure up to double its working pressure. Mr. Shock treats at great length the causes of the deterioration of marine boilers. His observations, however, are for the most part of too speculative and theoretical a character to have much practical value. Two Admiralty committees, presided over respectively by Admiral Sir George Elliot and Mr. James Wright, Engineer-in-chief of the Navy, have made boiler deterioration the subject of long and patient experimental inquiry, and both agree in finding that it is principally due to the action of the air having access to the boilers when not under steam, or being carried into them with the feed when under steam. They also consider that the greater deterioration in the boilers of the Royal Navy, as compared with those of the mercantile marine, is chiefly, if not entirely, owing to the fact that Her Majesty's ships are necessarily little under steam, and that their boilers are thereby much more exposed to the action of the moist air than those employed in the merchant service. The regulations in the "Steam Manual" have accordingly been modified and supplemented in accordance with their recommendations.

ELECTRIC LIGHT BY INCANDESCENCE.*

By JOSEPH W. SWAN.

SPEAKING in this place on electric light, I can neither forget nor forbear to mention, as inseparably associated with the subject and with the Royal Institution, the familiar, illustrious, names of Davy and Faraday. It was in connection with this institution that, eighty years ago, the first electric light experiments were made by Davy, and it was also in connection with this Institution, that, forty years later, the foundations of the methods, by means of which electric lighting has been made useful, were strongly laid by Faraday.

I do not propose to describe at any length the method of Davy. I must, however, describe it slightly, if only to make clear the difference between it and the newer method which I wish more particularly to bring under your notice.

The method of Davy consists, as almost all of you know, in producing electrically a stream of white-hot gas between two pieces of carbon.

When electric light is produced in this manner, the conditions which surround the process are such as render it impossible to obtain a small light with proportionally small expenditure of power. In order to sustain the arc in a state approaching stability, a high electromotive force and a strong current are necessary; in fact, such electromotive force and such current as correspond to the production of a luminous center of at least several hundred candle-power. When an attempt is made to produce a smaller center of light by the employment of a proportionally small amount of electrical energy, the mechanical difficulties of maintaining a stable arc, and the diminution in the amount of light (far beyond the diminished power employed), puts a a stop to reduction at a point at which much too large a light is produced for common purposes.

The often-repeated question, "Will electricity supersede gas?" could be promptly answered if we were confined to this method of producing electric light; and for the simple reason that it is impossible, by this method, to produce individual lights of moderate power.

The electric arc does very well for street lighting, as you all know from what is to be seen in the city. It also does very

* Lecture delivered at the Royal Institution of Great Britain, March 10, 1882.

well for the illumination of such large inclosed spaces as railway stations; but it is totallly unsuited for domestic lighting, and for nine-tenths of the other purposes for which artificial light is required. If electricity is to compete successfully with gas in the general field of artificial lighting, it is necessary to find some other means of obtaining light through its agency than that with which we have hitherto been familiar. Our hope centers in the method—I will not say, the *new* method—but the method which until within the last few years has not been applied with entire success, but which, within a recent period, has been rendered perfectly practicable—I mean the method of producing light *by electrical incandescence.*

The fate of electricity as an agent for production of artificial light in substitution for gas, depends greatly on the success or non-success of this method; for it is the only one yet discovered which adapts itself with anything like completeness to all purposes for which artificial light is required.

If we are able to produce light *economically* through the medium of *electrical incandescence*, in small quantities, or in large quantities, as it may be required, and at a cost not exceeding the cost of the same amount of gas-light, then there can be little doubt—there can, I think, be *no* doubt—that in such a form, electric light has a great future before it. I propose, therefore, to explain the principle of this method of *lighting by incandescence* to show *how it can be applied*, and to discuss the question of *its cost.*

When an electrical current traverses a conducting wire, a certain amount of *resistance* is opposed to the passage of the current. One of the effects of this conflict of forces is the development of heat. The amount of heat so developed depends on the nature of the wire—on its length and thickness, and on the strength of the current which it carries. If the wire be thin and the current strong, the heat developed in it may be so great as to raise it to a white heat.

The experiment I have just shown illustrates the principle of electric lighting by incandescence, which is briefly this—that a *state of white heat may be produced in a continuous solid conductor by passing a sufficiently strong electrical current through it.*

A principle, the importance of which cannot well be over-estimated, underlies this method of producing light electrically—namely, the principle of *divisibility.* By means of electric incandescence it is possible to produce exceedingly small centers of light, even so small as the light of a single candle; and with no greater expenditure of power in proportion to the light produced, than is involved in the maintenance of light-centers 10 or 100 times greater. Given a certain kind of wire, for example a platinum wire, the 100th of an inch in diameter, a certain quantity of current would make this wire white-hot whatever its length. If in one case the wire were one inch long and in another case ten inches long, the same current passing through these two pieces of similar wire, would heat both to precisely the same temperature. But in order to force the same current through the ten times longer piece, ten times the electro-motive force, or, if I may be allowed the expression, electrical pressure, is required, and exactly ten times the amount of energy would be expended in producing this increased electro-motive force.

Considering, therefore, the proportion between power applied and light produced, there is neither gain nor loss in heating these different lengths of wire. In the case of the longer wire, as it had ten times the extent of surface, ten times more light was radiated from it than from the shorter wire, and that is exactly equivalent to the proportional amount of power absorbed. It is therefore evident that *whether a short piece of wire or a long piece is electrically heated, the amount of light produced is exactly proportional to the power expended in producing it.*

This is extremely important; for not only does it make it possible to produce a small light where a small light is required, without having to pay for it at a higher rate than for a larger light, but it gives also the great advantage of obtaining *equal distribution* of light. As the illuminating effect of light is inversely as the square of the distance of its source, it follows that where a large space is to be lighted, if the lighting is accomplished by means of centers of light of great

power, a much larger total quantity of light has to be employed in order to make the spaces remotest from these centers sufficiently light, than would be required if the illumination of the space were obtained by numerous smaller lights equally distributed.

In order to practically apply the principle of producing light by the incandescence of an electrically heated continuous solid conductor, it is necessary to select for the light-giving body a material which offers a considerable *resistance* to the passage of the electric current, and which is also capable of bearing an exceedingly high temperature without undergoing fusion or other change.

As an illustration of the difference that exists among different substances in respect of *resistance* to the flow of an electric current, and consequent tendency to become heated in the act of electrical transmission, here is a wire formed in alternate sections of platinum and silver; the wire is perfectly uniform in diameter, and when I pass an electric current through it, although the current is uniform in every part, yet, as you see, the wire is not uniformly hot, but white-hot only in parts. The white-hot sections are platinum, the dark sections are silver. Platinum offers a higher degree of resistance to the passage of the electric current than silver, and in consequence of this, more heat is developed in the platinum than in the silver sections.

The high electrical resistance of platinum, and its high melting-point, mark it out as one of the most likely of the metals to be useful in the construction of incandescent lamps. When platinum is mixed with 10 or 20 per cent. of iridium, an alloy is formed, which has a much higher melting-point than platinum; and many attempts have been made to employ this alloy in electric lamps. But these attempts have not been successful, chiefly because, high as is the melting-point of iridio-platinum, it is not high enough to allow of its being heated to a degree that would yield a sufficiently large return in light for energy expended. Before an economical temperature is reached, iridio-platinum wire slowly volatilizes and breaks. This is a fatal fault, because *in obtaining light by incandescence there is the greatest imaginable advantage in being able to heat the incandescing body to an extremely high temperature.* I will illustrate this by experiment.

Here is a glass bulb containing a filament of carbon. When I pass through the filament *one unit* of current, light equal to *two candles* is produced. If now I increase the current by *one-half*, making it *one unit and a half*, the limit is increased to *thirty candles*, or thereabout, so that for this one-half increase of current (which involves nearly a *doubling of the energy* expended), *fifteen times more light* is produced.

It will readily be understood from what I have shown that it is essential to economy that the incandescing material should be able to bear an enormous temperature without fusion. We know of no metal that fulfils this requirement; but there is a non-metallic substance which does so in an eminent degree, and which also possesses another quality, that of *low conductivity*. The substance is carbon. In attempting to utilize carbon for the purpose in question, there are several serious practical difficulties to be overcome. There is, in the first place, the mechanical difficulty arising from its intractability. Carbon, as we commonly know it, is a brittle and non-elastic substance, possessing neither ductility nor plasticity to favor its being shaped suitaby for use in an electric lamp. Yet, in order to render it serviceable for this purpose, it is necessary to form it into a slender filament, which must possess sufficient strength and elasticity to allow of its being firmly attached to conducting wires, and to prevent its breaking. If heated white hot in the air, carbon burns away; and therefore means must be found for preventing its combustion. It must either be placed in an atmosphere of some inert gas or in a vacuum.

During the last forty years, spasmodic efforts have from time to time been made to grapple with the many difficulties which surround the use of carbon as the wick of an electric lamp. It is only within the last three or four years that these difficulties can be said to have been surmounted. It is now found that carbon can be produced in the form of straight or bent filaments of extreme thickness, and possessing a great degree of elasticity and strength. Such fila-

ments can be produced in various ways—by the carbonization of paper, thread, and fibrous woods and grasses. Excellent carbon filaments can be produced from the bamboo, and also from cotton thread treated with sulphuric acid. The sulphuric acid treatment effects a change in the cotton thread similar to that which is effected in paper in the process of making parchment paper. In carbonizing these materials, it is of course necessary to preserve them from contact with the air. This is done by surrounding them with charcoal.

Here is an example of a carbon filament produced from parchmentized cotton thread. The filament is not more than the .01 of an inch in diameter, and yet a length of three inches, having therefore a surface of nearly the one-tenth of an inch, gives a light of twenty candles when made incandescent to a moderate degree.

I have said, that, in order to preserve these slender carbon filaments from combustion, they must be placed in a vacuum; and experience has shown that if the filaments are to be durable, the vacuum must be exceptionally good. One of the chief causes of failure of the earlier attempts to utilize the incandescence of carbon, was the imperfection of the vacua in which the white-hot filaments were placed; and the success which has recently been obtained is in great measure due to the production of a better vacuum in the lamps.

In the primitive lamps, the glass shade or globe which inclosed the carbon filament was large, and usually had screw joints, with leather or india-rubber washers. The vacuum was made either by filling the lamp with mercury, and then running the mercury out so as to leave a vacuum like that at the upper end of a barometer, or the air was exhausted by a common air pump. The invention of the mercury pump by Dr. Sprengel, and the publication of the delicate and beautiful experiments of Mr. Crookes in connection with the radiometer, revealed the conditions under which a really high vacuum could be produced, and in fact gave quite a new meaning to the word vacuum. It was evident that the old incandescent lamp experiments had not been made under suitable conditions as to vacuum; and that before condemning the use of carbon, its durability in a really high vacuum required still to be tested. This idea having occurred to me, I communicated it to Mr. Stearn, who was working on the subject of high vacua, and asked his co-operation in a course of experiments having for their object to ascertain whether a carbon filament produced by the carbonization of paper, and made incandescent in a high vacuum was durable. After much experimenting we arrived at the conclusion that *when a well formed carbon filament is firmly connected with conducting wires, and placed in a hermetically sealed glass ball perfectly exhausted, the filament suffers no apparent change even when heated to an extreme degree of whiteness.* This result was reached in 1878. It has since then become clearly evident that Mr. Edison had the same idea and reached the same conclusion as Mr. Stearn and myself.

A necessary condition of the higher vacuum was the simplification of the lamp. In its construction there must be as little as possible of *any* material, and there must be none of such material as could occlude gas, which being eventually given out would spoil the vacuum. There must besides be no joints except those made by the glass-blower.

Therefore, naturally and per force of circumstances, the incandescent carbon lamp took the most elementary form, resolving itself into a *simple bulb, pierced by two platinum wires supporting a filament of carbon.* Probably the first lamp, having this elementary character, ever publicly exhibited, was shown in operation at a meeting of the Literary and Philosophical Society of Newcastle in February, 1879. The vacuum had been produced by Mr. Stearn by means of an approved Sprengel pump of his invention.

Blackening of the lamp glass, and speedy breaking of the carbons, had been such invariable accompaniments of the old conditions of imperfect vacua, and of imperfect contact between carbon and conducting wires, as to have led to the conclusion that the carbon was volatilized. But under the new conditions these faults entirely disappeared; and carefully conducted experiments have shown that

well-made lamps are quite serviceable after more than a thousand hours' continual use.

Here are some specimens of the latest and most perfected forms of lamp. The mode of attaching the filament to the conducting wires by means of a tiny tube of platinum, and also the improved form of the lamp, are due to the skill of Mr. Gimmingham.

The lamp is easily attached and detached from the socket which connects it with the conducting wires; and can be adapted to a great variety of fittings, and these may be provided with switches or taps for lighting or extinguishing the lamps. I have here a lamp fitted especially for use in mines. The current may be supplied either through main wires from a dynamo-electrical machine, with flexible branch wires to the lamp, or it may be fed by a set of portable store cells closely connected with it. I will give you an illustration of the *quality* of the light these incandescent lamps are capable of producing by turning the current from a Siemen's dynamo-electric machine (which is working by means of a gas engine in the basement of the building) through sixty lamps ranged round the front of the gallery and through six on the table. (The theater was now completely illuminated by means of the lamps, the gas being turned off during the rest of the lecture.)

It is evident by the appearance of the flowers on the table that colors are seen very truly by this light, and this is suggestive of its suitability for the lighting of pictures.

The heat produced is comparatively very small; and of course there are no noxious vapors.

And now I may, I think, fairly say that the difficulties encountered in the construction of incandescent electric lamps have been completely conquered, and that their use is *economically practicable*. In making this statement I mean, that, both as regards the *cost of the lamp* itself and *the cost of supplying electricity to illuminate it*, light can be produced at a cost which will compare not unfavorably with the cost of gas light. It is evident that if this opinion can be sustained, lighting by electricity at once assumes a position of the widest public interest, and of the greatest economic importance; and in view of this, I may be permitted to enter with some detail into a consideration of the facts which support it.

There has now been sufficient experience in the manufacture of lamps to leave no doubt that they can be cheaply constructed, and we know by actual experiment that continuous heating to a fairly high degree of incandescence during 1,200 hours does not destroy a well-made lamp. What the utmost limit of a lamp's life may be we really do not know. Probably it will be an ever-increasing span; as, with increasing experience, processes of manufacture are sure to become more and more perfect. Taking it, therefore, as fully established that *a cheap and durable lamp can now be made*, the further question is as to *the cost of the means of its illumination*.

This question in its simplest form is that of the more or less economical use of coal; for coal is the principally raw material alike in the production of gas and of electric light. In the one case, the coal is consumed in producing gas which is burnt; in the other in producing motive power, and, by its means, electricity.

The cost of producing light by means of electric incandescence may be compared with the cost of producing gas-light in this way—2 cwt. of coal produces 1,000 cubic feet of gas, and this quantity of gas, of the quality called fifteen-candle gas, will produce 3,000 candle-light for one hour. But besides the product of gas, the coal yields certain by-products of almost equal value. I will, therefore, take it that we have in effect 1,000 feet of gas from 1 cwt. of coal instead of from 2, as is actually the case.

And now, as regards the production of electricity. One cwt. of coal—that is the same measure *in point of value* as gives 1,000 feet of gas—will give 50 horse-power for one hour. Repeated and reliable experiments show that we can obtain through the medium of incandescent lamps at least 200 candle-light per horse-power per hour. But as there is waste in the conversion of motive power into electricity, and also in the conducting-wires, let us make a liberal deduction of 25 per cent., and take only 150 candle-light as the net available product of 1 horse-power; then for 50 horse-power (the product of 1 cwt. of coal), we

have 7,500 candle-light, as against 3,000 candle-light from *an equivalent value* of gas. That is to say two and a half times more light.

There still remains an allowance to be made to cover the cost of the renewal of lamps. There is a parallel expense in connection with gas lighting in the cost of the renewal of gas-burners, gas globes, gas chimneys, &c. I cannot say that I think these charges against gas-lighting will equal the corresponding charges against electric-lighting, unless we import into the account—as I think it right to do—the consideration that, without a good deal of expense be incurred in the renewal of burners, and unless minute attention be given, far beyond what is actually given, to all the conditions under which the gas is burned, nothing like the full light product which I have allowed to be obtainable from the burning of 1,000 cubic feet of gas, will be obtained, and, as a matter of fact, is not commonly obtained, especially in domestic lighting. Taking this into account, and considering what would have to be done to obtain the full yield of light from gas, and that if it be not done, then the estimate I have made is too favorable, I think but little, if any, greater allowance need be made for the charge in connection with the renewal of lamps in electric lighting than ought to be made for the corresponding charges for the renewal of gas burners, globes, chimneys, &c. But it will be seen that even if the cost for renewal of lamps should prove to be considerably greater than the corresponding expense in the case of gas, there is a wide margin to meet them before we have reached the limit of the cost of gas-lighting.

I think too it must be fairly taken into account and placed to the credit of electric lighting, that by this mode of lighting there is entire avoidance of the damage to furnishings and decorations of houses, to books, pictures, and to goods in shops, which is caused through lighting by gas, and which entails a large expenditure for repair, and a large amount of loss which is irreparable.

I have based these computations of cost of electric light on the supposition that the light product of 1 horse-power is 150 candles. But if durability of the lamps had not to be considered, and it were an abstract question how much light can be obtained through the medium of an incandescent filament of carbon, then one might, without deviating from ascertained fact, have spoken of a very much larger amount of light as obtainable by this expenditure of motive power. I might have assumed double or even more than double the light for this expenditure. Certainly double and treble the result I have supposed can actually be obtained. The figures I have taken are those which consist with long life to the lamps. If we take more light for a given expenditure of power, we shall have to renew the lamps oftener, and so what we gain in one way we lose in another. But it is extremely probable that a higher degree of incandescence than that on which I have based my calculations of cost, may prove to be compatible with durability of the lamps. In that case, the economy of electric lighting will be greater than I have stated.

In comparing the cost of producing light by gas and by electricity, I have only dealt with the radical item of coal in both cases. Gas-lighting is entirely dependent upon coal—electric lighting is not, but in all probability coal will be the chief source of energy in the electric lighting also. When, however, water power is available, electric lighting is in a position of still greater advantage, and, in point of cost, altogether beyond comparison with other means of producing light.

To complete the comparison between the cost of electric light and gas light, we must consider not only the amount of coal required to yield a certain product of light in the one case and in the other, but also the cost of converting the coal into electric current and into gas; that is to say, the cost of manufacture of electricity and the cost of manufacture of gas. I cannot speak with the same exactness of detail on this point as I did on the comparative cost of the raw material. But if you consider the nature of the process of gas manufacture, and that it is a process, in so far as the lifting of coal by manual labor is concerned, not very unlike the stoking of a steam boiler, and if electricity is generated by means of steam, then the manual labor chiefly involved in both processes is not unlike. It is evident that in gas manufacture it

would be necessary to shovel into the furnaces and retorts five or six times as much coal to yield the same light product as would be obtainable through the steam engine and incandescent lamps. But here again it is necessary to allow for the value of the labor in connection with the products other than gas, and hence it is right to cut down the difference I have mentioned to half—*i.e.*, debit gas with only half the cost of manufacture, in the same way as in our calculation we have charged gas with only one-half the coal actually used. But when that is done there is still a difference of probably three to one in respect of labor in favor of electric lighting.

I have made these large allowances of material and labor in favor of the cost of gas, but it is well known that the bye products are but rarely of the value I have assumed. I desire, however, to allow all that can be claimed for gas.

With regard to the COST OF PLANT, I think there will be a more even balance in the two cases. In a gasworks you have retorts and furnaces, purifying chambers and gasometers, engines, boilers, and appliances for distributing the gas and regulating its pressure. Plant for generating electricity on a large scale would consist principally of boilers, steam engines, dynamo-electric machines, and batteries for storage.

No such electrical station, on the scale and in the complete form I am supposing, has yet been put into actual operation; but several small stations for the manufacture of electricity already exist in England, and a large station designed by Mr. Edison, is, if I am rightly informed, almost completed in America. We are therefore on the point of ascertaining by actual experience, what *the cost of the works* for generating electricity will be. Meanwhile, we know precisely the cost of boilers and engines, and we know approximately what ought to be the cost of dynamo-electric machines of suitably large size. We have, therefore, sufficient grounds for concluding that to produce a given quantity of light electrically the cost of plant would not exceed greatly, if at all, the cost of equivalent gas-plant.

There remains to be considered, in connection with this part of the subject, the *cost of distribution*. Can electricity be distributed as widely and cheaply as gas? On one condition, which I fully hope can be complied with, this may be answered in the affirmative. The condition is that it may be found practicable and safe to distribute electricity of comparatively high tension.

The importance of this condition will be understood when it is remembered that to effectively utilize electricity in the production of light in the manner I have been explaining, it is necessary that the *resistance in the carbon of the lamps* should be relatively great to the *resistance in the wires which convey the current to them*. When lamps are so united with the conducting wire, that the current which it conveys is divided amongst them, you have a condition of things in which the aggregate resistance of the lamps will be very small, and the conducting wire, to have a relatively small resistance, must either be *very short*, or, if it be long. it must be *very thick*, otherwise there will be excessive waste of energy; in fact, it will not be a practical condition of things.

In order to supply the current to the lamps economically, there should be comparatively little resistance in the line. A waste of energy through the resistance of the wire of 10 or perhaps 20 per cent. might be allowable, but if the current is supplied to the lamps in the manner I have described—that of *multiple arc*, each lamp being as it were *a crossing between two main wires*, then—and even if the individual lamps ofiered a somewhat higher degree of resistance than the lamps now in actual use—the thickness of the conductor would become excessive if the line was far extended. In a line of half a mile, for instance, the weight of copper in the conductor would become so great, in proportion to the number of lamps supplied through it, as to be a serious charge on the light. On the other hand, if a smaller conducting wire were used. the waste of energy and consequent cost would greatly exceed that I have mentioned as the permissive limit.

Distribution in this manner has the merit of simplicity, it involves no danger to life from accidental shock; and it does not demand great care in the insulation of the conductor. But it has the great defect of limiting within comparatively small bounds the area over which the power for lighting could be distributed

from one center. In order to light a large town electrically on this system, it would be necessary to have a number of supply stations, perhaps half a mile or a mile apart. It is evidently desirable to be able to effect a wider distribution than this, and I hope that either by arranging the lamps *in series*, so that the same current passes through several lamps in succession, or by means of *secondary voltaic cells*, placed as electric reservoirs in each house, it may be possible to economically obtain a much wider distribution.

Whether by the method of multiple arc which necessitates the multiplication of electrical stations; or by means of the simple series, or by means of secondary batteries connected with each other from house to house in single series, the lamps being fed from these in multiple arc, I am quite satisfied that comparatively with the distribution of gas, the distribution of electricity is sufficiently economical to permit of its practical application on a large scale.

As to the cost of laying wires in a house, I have it on the authority of Sir Wm. Thomson, who has just had his house completely fitted with incandescent lamps from attics to cellars—to the entire banishment of gas—that the cost of internal wires for the electric lamps is less than the cost of plumbing in connection with gas-pipes.

I have expended an amount of time on the question of *cost* which I fear must have been tedious; but I have done so from the conviction that the practical interest of the matter depends on this point. If electric lighting by incandescence is not an economical process, it is unimportant; but if it can be established—and I have no doubt that it can—that this mode of producing light is economical, the subject assumes an aspect of the greatest importance.

Although at the present moment there may be deficiencies in the apparatus for generating and storing electricity on a very large scale, and but little experience in distributing it for lighting purposes over wide areas, and consequently much yet to be learnt in these respects; yet, if once it can be clearly established that, light for light, electricity is as cheap as gas, and that it can be made applicable to all the purposes for which artificial light is required, electric light possesses such marked advantages in connection with health, with the preservation of property, and in respect of safety, as to leave it as nearly certain as anything in this world can be, that the wide substitution of the one form of light for the other is only a question of time.

THE WEIGHTS OF FRAMED GIRDERS AND ROOFS.

By JOSEPH HAYWOOD WATSON BUCK, M. Inst. C.E.

From Selected Papers of the Institution of Civil Engineers.

THE attention of the author having been lately directed to various formulæ for obtaining the approximate weight of a girder or roof principal, he now proposes first to ascertain the limiting spans deduced therefrom, taking the same type in each case as the best means of comparison, and afterwards to suggest the application of general rules, which, he believes, would prove of great service in designing structures of this character, especially in saving time, while ensuring results as accurate as those obtained by the more laborious processes in general use.

With this view he will first observe that the weight of any bridging structure of which the weight is equally distributed, and which carries a fixed distributed load, is given by the following series:

Let W = the external load.

and W Q = the weight of a girder of the proposed type, of the strength required to carry W, but not its own weight in addition.

Then $W \times (Q + Q^2 + Q^3$ &c., *ad infinitum*) = the weight of such a girder of the strength required to carry W and its own weight in addition.

But the sum of this series $= \frac{Q}{1-Q}$.

Therefore $\frac{WQ}{1-Q}$ = the total weight of the girder.

Or, if $WQ=a$,

then $\frac{Wa}{W-a}$ = the total weight of the girder.

And the limiting span is reached when $Q=1$, *i.e.*, when $a=W$, the sum of the series being then infinity.

In a paper on the reconstruction of the Malahide Viaduct, Mr. W. Anderson, M. Inst. C.E., furnishes the following rule for roughly estimating the weight of a lattice girder of uniform strength, deduced from the distribution of the material in the girders used in that structure, which are of 52 feet span, the strain per square inch of the gross section of the booms being 4 tons, and the depth $\frac{1}{12.8}$ of the span.

Weight in lbs. per lineal foot of girder. } = { Three times the distributed load in tons.

Let W = the external load,
and L = the span.
Reducing to tons,

$\frac{3WL}{2{,}240}=\frac{WL}{747}$ = the weight of the girder in tons.

This estimate does not include the weight of the girder itself, but corresponds to a in the previous formula. Completing the series and reducing $\frac{WL}{747-L}$ = the total weight of the girder, and the limiting span is therefore 747 feet.

Professor Unwin, M. Inst. C.E., in his work "Iron Bridges and Roofs," gives the formula,

$$\frac{WLr}{Cs-Lr}=\text{the weight of the girder,}$$

C being a coefficient depending on the description of girder, r the ratio of depth to span, and s the strain in tons per square inch of the gross section of the booms.

For the Charing Cross bridge the value of C assigned by Professor Unwin is 1,880, and the depth measured between the centers of gravity of the booms is $\frac{1}{12.8}$ of the span, as before. Therefore, if the strain s be again taken as 4 tons per square inch, the formula after reduction becomes $\frac{WL}{589-L}$, and the limiting span is 589 feet.

The rule laid down by Mr. Benjamin Baker, M. Inst. C.E., in his "Long-span Railway Bridges," is $W\times\frac{t}{T-t}$; t being the strain in cwts. per square inch due to the weight of the girder itself, and T the strain in cwts. per square inch due to the entire load. His formula for the value of t in a lattice girder is,

$$0.03\frac{L^2x+2Lyd}{4d},$$

in which d is the depth in feet at the center, and x and y are coefficients depending upon the practical construction of the flange and web respectively, x being 0.93 and y being $2.7+0.001$ L.

Inserting the value of t found by this formula for the case of a girder the depth of which is $\frac{1}{12.8}$ of the span, and reducing the following quadratic equation is arrived at:—

$$Q=0.000001875\ L^2+9.001623\ L.$$

Let $Q=1$.
Then L = 417 feet, the limiting span.

For comparison with these results, it is now proposed to find a rule for the weight and limiting span of a lattice girder whose depth is $\frac{1}{12.8}$ of the span, as before, by means of an application of the formula at the commencement of this paper, using the data supplied by the weight of one of the girders of the Charing Cross bridge, with its load and span, as stated by Mr. B. B. Stoney, M. Inst. C.E., in his "Theory of Strains."
Let the weight of any girder $=g$, its span $=l$, and the external load $=w$.

Then $\frac{wQ}{1-Q}=g$, whence Q for the span $l=\frac{g}{w+g}$; Q for any other span $L=\frac{gL}{(w+g)l}$; the limiting span $S=\frac{w+g}{g}l$, and $\frac{WL}{S-L}=$ the weight of any other girder of the same proportions carrying any load W.

Also, when the external load is proportional to the span, as in the case of most bridges, and of roofs having principals the same distance apart in each instance; if

G = the weight of any other girder, &c., of the same proportions, $G = \frac{vL^2}{(S-L)l'}$.

The following details are quoted by Mr. Stoney:—Weight of girder, deducting end pillars, 184 tons; load on girder, 553.33 tons, exclusive of cornice, hand-rail, fish-plates, bolts, spikes, chairs for rails, hoopiron tongue and bolts for planking, and ballast. Span of girder, 154 feet. Calling the total external load 640 tons,

$$\frac{WL}{\left(\frac{640+184}{184}\times 154\right)-L} = \frac{WL}{688-L}$$

the weight of any other girder of the same proportion carrying any load W, and the limiting span is 688 feet (the weight here found is that between bearings only).

Summary.	Limiting Span. Feet.
Anderson (Malahide Viaduct)....	747
Buck (Charing Cross Bridge)	688
Unwin (" ")	589
Baker.....	417

Now, however useful such formulæ may be for the purpose of rough estimation, and for affording an approximate weight upon which to base, in the first instance, the calculations for a bridge or roof, there can be no doubt that, when the span is considerable, a great deal of time is usually consumed in afterwards so adjusting the final weight of the structure, that the strains per square inch shall neither exceed nor fall below the limiting strains; their scope also is necessarily very restricted. A system seems therefore to be called for by which, during the process of designing the structure, it may acquire, by successive accretions, due strength in each of its members; and, after, a short reference to the formula of Professor Rankine, for use in designing girders, the objections to which will be pointed out, the author proposes to describe a system which appears to fulfil the desired end.

Professor Rankine's formula, upon which he bases the proportions of each part of the girder, stands thus:

$$B = \frac{B's_1W'}{s_1W' - s_2B'},$$

W′ being the external working load, s_1 its factor of safety, s_2 a factor of safety suited to a steady load, B′ the weight of the girder as computed by considering the breaking load alone, s_1 W′; and B the total weight of the girder.

The whole of the external load is here considered as a moving load, the only fixed load being that of the girder itself. Now, in the first place it is certain that in a large bridge a great part of the load is fixed, and secondly, the moving load cannot be considered as provided for merely by the use of a factor of safety, the material introduced to meet the requirements of the moving load being distributed differently to that necessary for the fixed load. In fact, such a procedure is not applicable to open girders of any kind.

The method proposed by the author for proportioning the different members of a framed girder, or roof principal, of any materials, is based upon the following considerations:

Let the fixed distributed load = W, and WQ = a, as before.

Then, as before, $\frac{Wa}{W-a}$ = the total weight of a girder of the strength required to carry W, and its own weight in addition.

Let b = the weight of the additional material necessary to enable the girder to carry the moving load, but not the weight b in addition.

Then, by proportion, $\frac{(W+b)\,a}{W-a}$ = the weight of a girder of the strength required to carry W + b, and its own weight in addition.

There still remains the increment b, hitherto only considered as part of the fixed load, which must be retained to support the moving load.

Therefore the total weight of the girder becomes

$$\frac{(W+b)a}{W-a}+b;\ \text{or}\ \frac{W\,(a+b)}{W-a},$$

considered for practical purposes as consisting of the following elements:

$$\left(a\times\frac{W}{W-a}\times\frac{W+b}{W}\right)+b,$$

or c being the weight of a girder of the strength required to carry W + b, but not its own weight in addition; and equal to

$$\frac{(W+b)a}{W},$$

$\frac{(W+b)c}{(W+b)-c}+b$=the total weight of the girder; consisting of the following elements,

$$\left(c\times\frac{(W+b)}{(W+b)-c}\right)+b.$$

The application is as follows:

WHEN THERE IS NO MOVING LOAD.

(1.) Find the dimensions of each part of a girder of the strength required to carry the fixed load W, but not its own weight in addition, and note the sectional area of each member. Let the weight of this girder$=a$.

(2.) Multiply the sectional area of each member by $\frac{W}{W-a}$.

WHEN THERE IS A MOVING LOAD OR WIND PRESSURE ACTING LONGITUDINALLY, AS IN THE CASE OF A ROOF PRINCIPAL.

For Large Structures.

(1.) Find the dimensions of each part of a girder of the strength required to carry the fixed load W (including, in a bridge, its proportion of the floor, lateral bracing, rails, &c.), but not its own weight in addition, and note the sectional area of each member. Let the weight of this girder$=a$.

(2.) Multiply the sectional area of each member by $\frac{W}{W-a}$ (this step being taken at once, in some cases reduces the additional material for stiffening the struts accruing from the next steps).

(3.) Find the additional material required in each member to enable the girder to carry the moving load (in a roof to resist the action of the wind), and also in any new members which may be required for the same purpose, and note the sectional area of each member. Let the total weight of this additional material$=b$ (not to be added).

(4.) Multiply the sectional area of every member, except the new ones, by

$$\frac{W+b}{W}.$$

5. Add the additional material found in (3), assigning to each member the increment of sectional area due to it, and inserting the new members, if any.

For Small Structures.

(1). Find the dimensions of each part of a girder of the strength required to carry the moving load, but not its own weight in addition, and note the sectional area of each member. Let the weight of this girder$=b$ (merely note this).

(2.) Find the dimensions of each part of a girder of the strength required to carry $W+b$, but not its own weight in addition. Let the weight of this girder $=c$.

(3.) Multiply the sectional area of each member as found in (2) by $\frac{W+b}{(W+b)-c}$.

(4.) Add the material found in (1) allotting to each member the increment of sectional area due to it. If (1) has more members than (2), insert the additional members.

ON WEYRAUCH'S FORMULAS FOR THE STRENGTH OF MATERIALS.

By H. TRESCA.

Translated from Résumé de la Société des Ingenieurs Civils, Paris, for Abstracts of Institution of Civil Engineers.

THE question was primarily whether the known results of experiments up to the present time, considered together, were more correctly represented by the formulas used in France or by those proposed by recent German writers. This question was much simplified by recognition of one main point of difference in the practice of the two countries. It was the custom in France, in all experiments on the strength of materials, to determine not only the breaking strength, but also the limit of elasticity and the elongations which corresponded to those two critical conditions; and the limits of working stress were based upon the limit of elasticity. In Germany, on the contrary, the recent tendency had been to fix working stresses with regard to the breaking strength of the material.

Factors of safety, regulated by experience, were used by both parties.

It would seem that the limit of elasticity was the more rational basis for calculations, since it was more nearly allied to the actual working conditions of the material. Little difference, however, existed between the limits of working stress in common use, whatever the standard of reference. It would suffice for the purpose of discussion to examine that part of Dr. Weyrauch's paper which related to extension and compression alone. His method depended solely upon the breaking strength of the material, and ignored entirely the limit of elasticity. It did not seem reasonable, however, to consider one alone of the different properties of the material, whether that one was the breaking strength or the limit of elasticity. A close connection existed between both those elements of the question, and it remained to be seen whether the German formulas gave due weight to that consideration.

In Weyrauch's notation, a represented the intensity, or amount per unit area of section, of the "ultimate working strength," that was the breaking strength of the material under any given conditions, x, y, z, representing the circumstances in which the material worked, of which conditions a was a function; so that

$$a = f(x, y, z)$$

a was here the principal variable; while in France the breaking strength was usually considered constant, at least for definite varieties of material, t represented the intensity of breaking strength under statical load, or steady load applied once for all, and was called the "statical breaking strength"; u was called the "primitive strength," and was the greatest intensity of stress not producing rupture when indefinitely alternated with complete release from stress; and s, called "vibration-strength," was the greatest intensity of the stress not producing rupture when repeated in opposite senses alternately.

The most important point in Dr. Weyrauch's paper was the distinction between resistance to rupture by statical and repeated loading. Wöhler's experiments had shown u to be much less than t, but it was not so fully proved that a difference (similar in degree) existed between s and u. It was reasonable, however, to believe that if the effect of intermittent stress was greater than that of permanent stress, that of alternation of opposite stresses would be greater still. On the basis of the three coefficients, t, u, s, were founded those new formulas of resistance which had been used in Germany since Wöhler's experiments.

The author repeats at length the reasoning given in Dr. Weyrauch's paper, by which Launhardt's and Weyrauch's formulas had been arrived at, and goes on to remark that the series of equations which led to Launhardt's formula, relating to repetition of stress in one sense only, might cause it to be thought rational, although really empirical. The close correspondence between values given by it and certain experimental results of Wöhler accounted for its general use in Germany. But Weyrauch's formula still lacked confirmation by experiment. After a brief reference to Weyrauch's ingenious application of the formulas devised for simple longitudinal stress to long pillars liable to flexure, it is urged that the ideas on which the formulas in question were founded must be recognized as of great novelty and of real practical interest, and might be regarded as a first step towards a better comprehension in the future of the influence of repetition and alternation of stress on the working strength of materials. As yet they could not be said to be fully established, and being empirical in their character could only be judged by a comparison of their results with those sanctioned by experience. A typical example might be usefully quoted. Required the limiting intensity of stress to be adopted in the case of a bridge girder, for which the ratio of dead to total load was 1 to 3.5. The formula gave for answer 800 kilograms per square centimeter, and that was precisely the value which would have been fixed by practical judgment alone without calculation.

Wöhler's experiments were valuable in directing attention to the changes which might occur in the constitution of materials, but they did not conclusively show that breaking strength was a safer basis for limits of working stress than the

limit of elasticity. Experience with wrought-iron axles showed that after being successively twisted and untwisted a great many times a fibrous structure was developed which was not at first visible. The facets seen, when fractures thus produced were microscopically examined, were apparently caused by the rubbing together of the ends of the fibers previously broken in detail. From Wöhler's experiments it appeared that similar, though less marked, changes in molecular arrangements occurred much before rupture. The author admitted that the limit of elasticity was not a constant quantity; experiments on the flexure of rails, made by himself, having shown that the material remained elastic up to the stress to which it was last subjected. Nevertheless, the possibility of artificially raising the limit of elasticity was of little or no advantage to the material, since its condition then approached that of a brittle substance, and the same faith could not be placed in its permanent durability when strained. Wöhler's experiments furnished no evidence that repetition of stress below the elastic limit produced changed molecular relations in the material. Until proof of such changes was obtained the empirical formulas of Launhardt and Weyrauch could not be accepted, and the primitive limit of elasticity would remain the safest and most natural basis for the working formulas of resistance.

In conclusion, M. Tresca draws attention to the fact that, at the Conservatoire des Arts et Métiers, there are some plate-dynamometer springs which have been employed in experimental service for the last thirty years, and had in that time suffered rapidly repeated deflections, which might now be numbered by millions. The greatest permitted deflection of these springs corresponded nearly to their elastic limit, and as yet no signs of deterioration were visible. He thought the objections raised against the limit of elasticity, as a basis for working stress, had been effectually refuted, providing that in all cases when it was so employed the primitive elastic limit suffered no alteration.

By T. Seyrig.

Dr. Weyrauch's method of calculating dimensions, was founded upon a long series of experiments, made by Wöhler between 1858 and 1870, and repeated later by Spangenburg. Certain propositions had been deduced by the former from his own experiments, which were known collectively as Wöhler's law, and were thus expressed:

1. A piece experiencing repeated applications of stress alternating between certain maximum and minimum values, ultimately breaks under a less intensity of stress than would produce rupture if gradually applied once.

2. The number of repetitions producing rupture increases as the maximum stress is diminished, the minimum stress to which the piece returns after each repetition remaining constant.

3. The number of repetitions producing rupture increases as the minimum stress is increased, the maximum stress remaining constant.

4. When the maximum intensity of stress does not exceed a certain limit, a, rupture does not occur, whatever the number of repetitions.

5. That limiting intensity, a, increases as the minimum stress is increased.

The author exemplifies these propositions separately by the results of some of the experiments, and also illustrates 2 and 3 by diagrams in which the number of repetitions required for rupture are represented by ordinates whose corresponding abscissas represented the variable maximum or minimum stresses which alternated with a fixed minimum or maximum stress respectively. The experiments were made chiefly on specimens of iron and steel from the Phönix and Krupp Works, and, though not numerous or embracing much variety of material, sufficed to show a much greater similarity between the nature of iron and steel than had been hitherto supposed. Thus the ratio of s to u was, for wrought iron $\frac{7}{12}$, and for steel, $\frac{8}{15}$. It was necessary to observe that, owing to the very rapid repetition of the stress, there was no interval of repose between its successive applications. In large metallic structures such intervals usually occurred, and it might be that the disturbed molecules then returned more completely to their primitive positions and condition of resistance—an important question that remained for future investigation. A table is given, containing all the

values of the constants a, u and s, which the experiments had furnished; and a detailed explanation of certain formulas devised by Prof. Winkler, upon the basis of those values, which might suit intermediate values of a, more exactly than those of Launhardt and Weyrauch, comparing them with the latter both graphically and numerically. The author admits the importance of the limit of elasticity, but thinks that Wöhler's experiments showed the need for fully considering the conditions under which the forces were applied to the pieces of a machine or structure; in the former, quick repetition and motion; in the latter, the varying conditions produced by the moving load. Most specifications prescribed the minimum breaking strength and corresponding elongation, but not usually the limit of elasticity. It now appeared, however, that the latter was not constant, M. Tresca having found that it might be raised to near the limit of rupture; and under certain conditions of alternating opposite stresses, Wöhler had found rupture to occur below the primitive value of the elastic limit, which under these conditions must have been lowered. Wöhler's experiments required further confirmation, but still they sufficed to discredit those uniform limits of working stress, the use of which was at least as unfavorable to economy as to security. For if the conclusions of Launhardt, Weyrauch, and Winkler were accepted, a limiting stress, double of that hitherto adopted in France, might, in some cases, be worked to with the same margin of safety, thus giving greater economy; while in other cases two-thirds only of the usual limiting stress appeared permissible; many existing structures being therefore less secure than had been supposed.

By E. E. Marche.

Although the experiments of Wöhler had been made too carefully to permit doubt, either of their accuracy or of the truth of the law founded upon them, it was otherwise with the new formulas deduced from that law by other German writers, and they should not be accepted without investigation. The existence of the "primitive strength" u, was a direct conclusion from Wöhler's experiments, and Mr. Seyrig's diagrams showed it to be the abscissa of the vertical asymptote to the curve representing the variation in the number of repetitions of any given stress required to produce rupture, and its accurate determination, was necessarily difficult. After quoting in detail some experiments of Wöhler's on Phönix iron and Krupp steel by repeated flexure, the author infers that, from the entire number of experiments made, two values only of u could be deduced, viz., 22 kilograms per square millimeter for wrought iron, and 37 kilograms for steel. These were, sensibly, the primitive limits of elasticity of the some materials, and it was indeed remarkable that the German experimenters should propose to supersede the limit of elasticity by a new constant, which was only the same thing under another name. That rupture necessarily followed the repeated application of stress above the limit of elasticity he thought was scarcely yet fully proved. He conceived that when rupture occurred through repetition of stress below the statical breaking strength, it was due to alteration in the molecular state of the material, produced by vibration and manifested by diminished cohesion or by displacement of the limit of elasticity. Future experiments should tell something more than the mere number of repetitions required to produce rupture. After a certain number of repetitions the limit of elasticity and breaking strength should be again determined, in order to ascertain whether and to what extent their primitive values had been altered. Wöhler's experiments showed with certainty that stress below the elastic limit may be alternated an indefinite number of times with any less stress of the same sense, or with zero, without fear of rupture or molecular alteration of the material. But the experiments on alternate tension and compression which had led to the coefficient s and Weyrauch's formula deserved serious attention, and suggested the need for diminished limits of working stress in such circumstances. He held that, for repeated stress of one sense only, it was sufficient to fix the working stress at one-third of the limit of elasticity; and that, in the case of alternations of equal stresses of opposite

senses, one-third of the value found for s might be used.

The facts which had been ascertained by M. Tresca and others, relative to permanent deformation were of great importance, but since they only existed when and because the elastic limit was passed, they should not be used as data for calculating the strength of materials which, by the very conditions of their employment, were required to remain elastic and not to become modified or deformed.

By E. Trelat.

The author believes the limit of elasticity to be a more satisfactory basis for limits for working stress than the breaking strength. The business of an engineer was to so design the different members of a structure that the greatest loads should produce no visible permanent changes of their form and dimensions. For brittle materials, such as stone, which suffered no permanent change of form before breaking, deformation was proportional to the force producing it up to rupture; and it was therefore right to fix the safe working load as a fraction of the breaking strength. For those materials which could experience permanent deformation before rupture, experiment had shown their resistance to comprise two distinct periods, in the first of which they were elastic, while in the second they suffered permanent change of form. The boundary between those two periods, in other words the primitive limit of elasticity, marked the limit of safe employment for such materials with due regard to preservation of their form and dimensions; and the safe working stress should be taken as a fraction of that primitive limit. If the limit of elasticity was artificially raised the working stress should be a smaller fraction of that new limit. Future experiment in such special cases as that of repeated alternation of stress in opposite senses, might show to what extent the primitive limit of elasticity was lowered, or perhaps that it coincided with the breaking strength under those conditions. The existence of the different limits of rupture indicated by the symbols t, u, s, did not diminish the utility of the limit of elasticity as a standard of working resistance; but showed that its character should be accurately determined and the factor of safety fixed with due regard to circumstances.

By H. Matthieu, President of the Society of Civil Engineers of Paris.

Experiments made by the author 25 years age showed that, by successive applications of stress, at first feeble and gradually increased by very small and equal increments, the breaking strength was raised above the primitive value. But when this process was commenced with an initial stress equal to half the primitive breaking strength, rupture was produced by less stress than in the first case. The limit of elasticity seemed, therefore, to vary according to the manner in which it was sought for.

While rendering full justice to the remarkable labors of the German experimenters, M. Matthieu thinks that French engineers will retain their belief in the principle of the limit of elasticity, which in France had served hitherto as the basis of the theory and the practical formulas of the strength of materials.

REPORTS OF ENGINEERING SOCIETIES.

American Society of Civil Engineers — This Society met, Wednesday, Oct. 18th, 1882, at 8 p.m. Vice-President, Wm. H. Paine in the chair, John Bogart, Secretary. The death of Henrique Harris, M. Am. Soc. C. E., on Oct. 10th, was announced and the preparation of a memoir was directed.

A paper by Henry D. Blunden, M. Am. Soc. C. E., on the *Care and Maintenance of Iron Bridges*, was read by the Secretary. The writer observed, that while many papers and much discussion had been published on the design and construction of bridges, there had been little or nothing on the subject of their care and maintenance after erection. Indeed, there seems a prevalent idea that once erected, they will last forever with no care but an occasional coat of paint and even that is often not attended to. A close examination during nine years past, of a large number of bridges shows constant, shameful neglect. The fact is that the immediate care of bridges is generally left to men who know nothing, either practically or theoretically, of their design or manufacture. The single idea is to screw everything up tight and to replace all rivets without asking why a rivet drops out several times in the same place.

The paper enumerated various causes of undue wear in bridges; uneven bearing of rails and ties; insufficient freedom of expansion gear often caused by accumulation of dirt; im-

proper anchoring of fixed ends; poor masonry: uneven adjustment of laterals; uneven bearing of suspended floors; over tightening of counters; corrosion of iron; false economy in construction of floors, rendering renewals very expensive; too large joints between ends of rails.

The writer also gives a number of suggestions as to the proper care of bridges, particularly insisting upon constant inspection and frequent reports to the office of the Chief Engineer.

The paper was discussed by Messrs. C. Macdonald, S. H. Shreve, Thos. Cooper, Wm. H. Paine, J. P. Davis, W. E. Worthen, J. G. Sanderson, C. E. Emery and J. C. Campbell In the discussion the great necessity of attention to the care of bridges in use was forcibly brought out. Instances were mentioned of the serious results of entrusting this duty to incompetent men and of the advantage found by the few corporations now taking proper measures. Reference was made to the great difficulty of adjustment in bridges with parts in cast and parts in wrought iron. A case was described in which an iron rod in contact with sulphur became seriously corroded. It was stated that the ordinary commercial sulphur had an amount of sulphuric acid sufficient to cause rust, but that when properly washed it was safe. The use of sulphur or lead for joints was discussed. An ordinary misapprehension as to scale was illustrated by an instance where the actual amount of iron in the scale was found to be but one-tenth of the scale. The use of lime whitewash to protect iron was considered, and instances of its good effect were mentioned.

ENGINEERS' CLUB OF PHILADELPHIA.—The first meeting of the season was held Oct. 7th. President Rudoldph Hering in the chair.

Mr. W. H. Cory, of England, read a paper upon the subject of his process for the utilization of waste dust coal, which consists of mixing the coal with a small percentage of fine, dry fire-clay and another small percentage of silicate of soda, and submitting the block to a pressure of one ton to the square inch. The blocks are then stacked to dry and in 24 hours (the chemical action of the alumina in the clay having converted the silicate of soda into silicate of alumina or into an insoluble substance, in that time) the blocks are fit for use, and are as hard as ordinary coal. Among the advantages claimed for this fuel are the following; seven per cent. more work than ordinary lump coal, there being no loss from dust falling through the fire-bars, &c.; that the fuel manufacturer can make his own silicate at little expense and trouble; that the fuel, being compressed, will stow in a much less space than coal; that it does not smoke, smell, depreciate in the furnace or cause clinker; that the machinery is light and inexpensive; that the cost of manufacture will not exceed fifty cents per ton, and that all descriptions of coal can be utilized, without deteriorating their burning qualities. Mr. Cory exhibited samples made from Anthracite, Bituminous and Lignite coals, and concluded by giving statistics showing annual waste of coal in dust, etc.

The secretary presented from Mr. H. M. Geer, a discussion of that part of Mr. P. H. Baermann's recent paper upon the "Thickness of Cast Iron Pipe under Pressure," wherein he refers to the rupture of a 12" pipe by the ram upon the sudden closing of a 2½" opening, under 230' head, by the breaking of a hydrant. For Mr. Baermann's formula, $\frac{W v^2}{2 g}$ giving a pressure of 2,330 lbs. per square inch, Mr. Geer substitutes $\frac{W v^2}{2 g} = P s$ (P= force or resistance and s = space over which P acts) or $P = \frac{W v^2}{2 g s}$ and obtains, assuming that the moving mass of water is brought to rest with a uniformly retarded motion, in one second 1,354 lbs. per square inch, in one-helf second 2,708 lbs. per square inch, and so on, inversely as the time. Without knowing the actual time of the closing of the valve and velocity of water, he considers deductions impossible. He refers to the reasoning of Mr. Fanning (Water Supply, p. 449) in this connection, as likewise erroneous. He attributes the cause of failure to thin, chilled and imperfect pipe, and the general safety of pipes from effects of the ram to the existence of air chambers at summits of undulations, the possible reflux of water to the reservoir, the compressibility of the yarn in the joints and perhaps to the elasticity of the walls of the pipe and the compressibility of the water itself.

The Secretary presented, for Mr. Howard Constable, a description of the Kinzua Viaduct, the highest bridge structure in the world, illustrated by numerous general and detail drawings and photographs. It forms part of a branch of the Erie Railway into the coal fields of Elk Country, Pa., and its construction was found to be the most economical way of crossing the Kinzua Gorge, a long time obstacle in the way of railroad construction.

Surveys and investigations leading to the conception of this work, were made by Mr. O. W. Barnes, Chief Engineer of the road before it passed into the hands of the Erie Railway. It was built according to Erie specifications, by Messrs. Clarke, Reeves & Co., under Mr. O. Chanute, Chief Engineer, assisted by Messrs. Chas. Pugsley, H. C. Keifer and the author. It contains 3,500,000 lbs. of iron and cost $275,000.

At the meeting of October 21st, Col. Livingstone, of Philadelphia, described the system of Driven Wells, giving various data and statistics, with regard to results obtained in this and other localities.

Dr. H. M. Chance described several horseshoe or ox bow bends occurring in the streams of Western Pennsylvania, attributing the origin of each and every similar loop to synclinal axes.

Loops on the Allegheny River at Brady's Bend and at Scrubgrass (also an old abandoned loop at Parker, two hundred feet above the present Channel); on the Red Bank Creek near Bethlehem; on Kettle Creek in Clinton County, and old abandoned bends at Callensburg on the Clanin River, and near Westport in Clinton

County, were described, the inevitable synclinal axis present at all of them, affording the only explanation of their origin.

ENGINEERING NOTES.

BLASTING WORK IN THE DANUBE.—The construction of the railway bridge across the Danube at Peterwardein involves a large amount of blasting in the bed of the river, which operations are now being carried out under the direction of Major Lauer, and at the expense of the contractors for the bridge, the Fives-Lille Company. The rock upon which part of the fortress of Peterwardein is built descends pretty steeply into the Danube. One of the piers of the bridge will have its foundation on this rocky slope, and it has been found necessary to level the rock for a length of 65 feet and a breadth of 26 feet, in order to be able to lower with the requisite precision the caisson for the pier foundation. As the rock to be removed is 23 feet below zero and the present level of the Danube about 40 feet below water, and as the current is running at a speed of 10½ feet per second, some idea may be formed of the difficulties of the blasting work to be done. The method employed by Major Lauer is consequently well suited to the operations needed; but as even with that method considerable difficulties arise, it has been found necessary, in this case, to construct, in the first place, a guide-rod of a length of 65 feet, which should resist the strong current to such an extent as to permit of the several dynamite charges being sunk with the greatest accuracy. After several experiments, a guide-rod has now been constructed which meets the requirements of the case, and enabled the workers to begin blasting operations on August 21. As upwards of 10,000 cubic feet of rock have to be removed, the work of blasting will probably last about forty days, and thus an opportunity will be offered for testing Major Lauer's method on a large scale.

THE FORTH BRIDGE.—In Section G (Mechanical Science) of the British Association meeting at Southampton, Mr. B. Baker read a paper on the Forth Bridge, in which it was stated that the report of the Anthropometric Committee showed that the average stature of a new-born infant was 19.34 in., while the average height of the Guardsmen sent out to Egypt was officially given at 5 ft. 10½ in. These figures had a ratio of 1 to 3.65, and as the largest railway bridge in this country—the Britannia Bridge—had a span of 465 ft., and the Forth Bridge a span of 1,700 ft., the ratio there was also 1 to 3 65. Hence to enable any one to appreciate the size of the Forth Bridge the following simple rule-of-three sum was suggested:—As a Grenadier Guardsman is to a new-born infant so is the Forth Bridge to the largest railway bridge yet built in this country. Bridges a few feet larger in span than the Britannia has been built elsewhere, but they were baby bridges after all. It was not the physical features of the country, but the habits of the population that rendered the construction of a 1,700 ft. span expedient. The Act for constructing a bridge at Queensferry across the Forth was obtained in 1873, and the contract for the construction of Sir Thomas Bouch's great suspension bridge in two spans was made, the preliminary works being in progress when the Tay Bridge fell. In consequence of the latter disaster, the directors of the Forth Bridge Company decided not to proceed with the works, and an Abandonment Bill was promoted in the Session of 1881. Different railway companies, interested in securing direct communication with the North of Scotland, objected to the abandonment of the enterprise, and instructed their consulting engineers, Messrs. J. Fowler, Harrison, and Barlow, to report anew on the practicability and cost of crossing the Forth by a bridge or otherwise, at Queensferry or elsewhere. A careful reinvestigation of the whole question was accordingly made, with the result that the directors were advised that it was perfectly practicable to build a bridge across the Forth which would comply with the requirements of the Board of Trade and public safety, and that the best place of crossing was Queensferry. The Abandonment Bill, which had passed the Commons, was then withdrawn, and the engineers were instructed to agree on a design. Modifications of the original suspension bridge were then considered, and Mr. Fowler and the writer of the paper submitted a project for a bridge on the continuous-girder principle. Messrs. Harrison and Barlow, fully appreciating the advantages which would pertain to such a bridge, as compared to a more or less flexible suspension bridge, made independent investigations, and suggested several modifications, and finally the design, a model and plans of which were now before the meeting, was unanimously agreed upon by all to be recommended to the directors for adoption. The directors acted upon this recommendation, and the necessary plans were deposited, and an Act obtained this year for constructing a continuous-girder bridge across the Forth at Queensferry, having two spans of 1,700 ft., two of 675 ft., fourteen of 168 ft. and six of 50 ft., and giving a clear headway for navigation purposes of 150 ft. above high-water spring tides. For this work Mr. Fowler and the author of the paper were acting as engineers. Every one, probably, would concede that a girder-bridge would prove stiffer than a suspension bridge, but it was not so obvious that it would be cheaper. Careful comparative estimates had, however, proved this to be so in the case of the Forth Bridge. Having explained the reasons which induced the engineers to fix on the length and width and other matters connected with the design of the bridge, the paper stated that the superstructure would be of steel. For the tension members the steel used was to have an ultimate tensile strength of not less than 30 tons, nor more than 33 tons per square inch, with an elongation of 20 per cent. in a length of 8 in. For the compression members the strength was to be from 34 tons to 37 tons, and the elongation 17 per cent. In making the tubes and other members, all plates and bars which can be bent cold were to be so treated, and where

heating was esssential no work was to be done upon the material after it had fallen to a blue heat. The steady pressure of hydraulic presses was to be substituted for hammering where practicable, and annealing would be required if the steel had been distressed in any way. Having given details in reference to the bridge compared with others, the paper stated that no special difficulty would arise with respect to the foundations. The total length of the great continuous-girder was 5,330 ft., or, say a mile. and of the viaduct approaches 2,754 ft., or rather over half a mile. The piers would be of rubble masonry, faced with granite, and the superstructure of iron lattice girders, with buckled-plate floor and trough-rail bearers, as in the instance of the main spans. The main girders spaced 16 ft. apart would be placed under the railway, and there would be a strong parapet and wind screen to protect the trains. About 42,000 tons of steel would be used in the superstructure of the main spans, and 3,000 tons of wrought iron in that of the viaduct approach. The total quantity of masonry in the piers and foundations would be about 125,000 cubic yards, and the estimated cost of the entire work upon the basis of the prices at which the original suspension bridge was contracted for, was about £1,500,000, though, owing to the magnitude and novelty of the undertaking, the estimate must be taken as approximate only, as a contract had not yet been concluded for the works.

RAILWAY NOTES.

A CAPITAL of about eight millions would suffice to construct the Euphrates Valley Railway, including, the *Nautical Gazette* thinks, stations and plant, and upon this sum dividend earnings should not be impossible. In the worst case a guarantee of 4 per cent. interest would only cost Government the inconsiderable sum of £320,000 per annum, compared with which the political avantages to be obtained are immeasurably more consequential; indeed cannot be weighed in the same balance. Besides which, the saving of seven days in the passage of India would enable Government to effect several economies in administration, and in all probability to more than save the actual outlay. About the strategic advantage of a quick alternative route which would make us to some extent independent of the Canal there can be no two questions. It would enable us to govern India twice as efficiently and ten times more safely than at present, while it would do more than anything else to secure the peace of Europe. Egypt and the Suez Canal would then lose much of their political significance, and it might be possible for continental nations—then no longer jealous of England—to come to look upon the Canal in the light of a commercial water way only. All do not think with the *Nautical Gazette*.

A PAPER in the *Revue Scientifique* (Paris, Sept. 2) on the railways of Europe, gives a number of interesting data. In 1840, America had 2,800 miles of railway in working; England, 1,275 miles; France, 310 miles; Germany, 290 miles; Belgium, 200 miles; Austro-Hungary, 89 miles; Russia, 16½ miles; and Holland, 11 miles. In 1860, the United States possessed nearly as many miles of track as the whole of the European system, having 30,460 miles, against a European total of 31,700 miles; England was a long way ahead of Germany in the length of her system, and France was much behind. In 1870 these conditions were altered. During the ten years the European systems had more than doubled their mileage, which then had a total of 64,700 miles, America at the same time having only 52,450. England still retained the lead in Europe, and Germany and France followed her at a considerable distance, Germany, however, being little in advance of France. In 1878 Germany possessed a much longer system than England, having 19,260 miles against our 17,100. On December 31, in that year, Europe had 98,060 miles; the United States, 81,650; India, 7,530; Canada, 7,890; and Algeria, 465 miles. The United States had the greatest mileage in proportion to the population, having a little over twenty-one miles for each 10,000 persons, and were followed by Canada with 16½ miles. In Europe, Sweden took the lead with 6½ miles to 10,000, England only having 5⅛ miles. The number of locomotives running at the same period over all the lines referred to was 30,079, represeting a force of ten million horse power.

IRON AND STEEL NOTES.

ENGLISH IMPORTATION OF IRON.—Almost unnoticed, a startling change has, during the last few years, taken place in the metallurgical world. The iron manufacturers of Great Britain have come to depend in very great degree upon foreign nations for a large part of their raw materials. If we look back twenty years we shall find that the iron that was made in Great Britain was made almost exclusively of that smelted from our own ores; but this is far from being the case now. A few figures will show how great has been the growth of the demand for iron ore from other parts. In 1861 we imported 23,408 tons of iron ore, all, except a few hundred tons, being brought from Spain. Taking the importations in the total for periods of five years from that date, we find that by the year 1866 the importation had risen to 49,360 tons, and by the year 1871 to 335,033 tons. Again, in 1876 it was 673,235 tons, and in 1881 it was 2,450,696 tons; so that, roughly speaking, it doubled itself in every year named, except that in the last of the periods there was an increase much more than threefold. And it is worthy of note that Spain still supplies the great bulk of the ore thus brought in, for last year 2,227,486 tons were imported from that country, Italy and Algiers sending in the bulk of the remainder. Sweden used to send us large quantities of iron ore, but for the last seven or eight years it has sent us none; and Norway, once a large source of supply, sent us only 118 tons last year; so that it is from the

countries of Southern Europe and Spain that our supplies are drawn.

The growth of the use of imported ores is due to one cause, the increase of steel production. Until the basic process was commenced it was tolerably clear that the great bulk of the iron ores of Britain were not suitable for use in the steel manufacture; and thus as the use of steel grew there was an inevitable use of ores that were so fit. The rich districts of Furness and that of West Cumberland had ores that were so usable, and there was a continuous growth of the production of these; but there was a call beyond that that they could supply. And, moreover, many of the works that were on the coast could bring ores from Spain by sea cheaper than they could bring those by land, so that there arose the vast demand for ore that has caused the swelling of the imports shown in the figures above given, and that seems likely to continue, though probably not with such rapidity. There is now a systematic attempt to utilize our own ores by the basic process, and this will allow a portion of the steel that we use to be smelted from our own iron, and thus will at least lessen the rapidity of the growth of the imports of iron. But the fact that we use about 2,500,000 tons of ore from other nations, and that they cost with the carriage probably £1,500,000, is one that should be a very great inducement towards the further development of any and every system that will allow of the increasing use of our own resources, and that would retain a very large amount of money in this country. It is not to be expected that any such change will be very rapid. The imported ore and its product has made itself well known; that made by the basic process from our own ores has yet to win its way in many quarters. But whilst there has been only one large extension, that of Esten, where the process has been in use, there is now in course of construction one that will be equally large, and that will, in the course of a very few months, materially add to the production, whilst in the Shropshire and Staffordshire districts new works are in course of construction or in contemplation, and by these the basic process of steel production will be much extended, and the use of our own ores in the steel manufacture will be extended. It remains to be seen what effect the extension will have on the importation of ores; in the past that importation has been affected by political events in Spain, and that cause alone should induce as much as possible the substitution of our own ores for those the continuance of the supply of which has been broken at times.—*The Builder.*

THE following information respecting car wheels and car wheel iron has been published by Messrs. Whitney and Sons, of Phila delphia, makers of wheels. Concerning the Hamilton process, which consists of melting together charcoal and anthracite pig irons with Bessemer steel ends, the firm claims:—"It has been fully demonstrated that the use of steel brings into service many charcoal irons that would not otherwise be available for making wheels on account of their deficient strength or absence of chilling qualities, that a percentage of anthracite or coke irons may be used without impairing the strength or durability of the wheel, and that steel is better than white iron to bring up the chill in any wheel mixture." The greatest recorded mileage made by Whitney wheels, with the use of steel, is 178,000 miles, and this is the greatest mileage on the Pennsylvania railroad wheel records up to 1876. It is probable that since that time a much higher mileage has been obtained of which there is no accessible record. Memoranda of tests of wheel mixtures of charcoal irons and steel, wrought and anthracite iron are added thereto:—

Charcoal with	Tensile per sq. in.	Transverse.	Deflection.
2½ per cent. steel.....	22,467	7925	.00157
3⅜ per cent. steel	26,733	9538	.00185
6½ per cent. steel.....	24,400	7938	.00218
6¼ per cent. anthracite...			
7⅛ per cent. steel.....	28,150	9425	.00224
7½ per cent. anthracite...			
2½ per cent. steel.....			
2½ per cent. wrought iron	25,550	8750	.00221
6½ per cent. anthracite...			
5 per cent. steel.....			
5 per cent. wrought iron	26,500	8200	.00284
10 per cent. anthracite...			

The deflection is given in decimals of an inch per 1000 lbs. of load. Transverse strength is reduced to show weight required to break a bar 1 inch square, supported at one end, the weight being applied 1 inch from point of support. The average tensile strength per square inch of charcoal irons used for car wheels is 22,000 lbs.

ORDNANCE AND NAVAL.

IMPROVED COMPOUND ARMOR PLATES.—Experiments with composite armor-plates have shown that the cracks round the points of impact projectiles are more numerous, longer, and deeper, the greater the degree of hardness possessed by the steel employed, while steel below a certain point of hardness does not show any cracks, but, on the other hand, has a power of resistance scarcely above that of ordinary iron. With the view of preventing the formation of cracks, and of rendering practicable the employment of a steel as hard as possible and of the required degree of resistance, Herr H. Reusch, of Dillingen, exposes the armor-plates, after the steel face has been cast on, and at any stage of the subsequent rolling, for several days to a glowing heat in an annealing furnace, the steel face being covered as air-tight as possible, with a substance giving off oxygen, for instance, pure oxides of iron. It is stated that by this process the steel face of the plate—according to the duration of the heating process and the effectiveness of the substance giving off oxygen used—is more or less decarbonized, and converted into a very soft and extremely tough material, in which cracks are not produced by the impact of projectiles. In order to effect a close union between the bottom plate (soft steel

or iron) and the hard steel face cast on to it, the inventor employs easily fluxing silicates or borates as welding agents. They are applied either dissolved in water or as powder. The invention of Herr Reusch is protected by patent.

SOME important trials have recently been made in the Keyham Basin, Devonport, with the Audacious ironclad, the new flagship for the China station. Booms had been rigged out from the starboard side of the ship, varying in length from 30 ft. to 40 ft., and from these were hung wire nets protecting the whole side of the vessel. When the booms were lowered there were 18 ft. of netting submerged, enough to defeat the action of any torpedo, as from experiments it has been found that the destructive radius of torpedoes does not exceed 10 ft., and that when they are exploded at a greater depth the weight of the water takes the explosion downwards. The working of the booms was most satisfactory, demonstrating that the nets afford effectual protection.

BOOK NOTICES

PUBLICATIONS RECEIVED.

THROUGH the politeness of Mr. James Forrest, Secretary of the Institution of Civil Engineers, we have received the following papers:

A Composite Screw Tug Boat. By John Augustus Thompson, Student I. C. E.

The Independent Testing of Steam Engines. By John George Mair, M. I. C. E.

Bo'ness Harbor and Dock Works. By Patrick Walter Meik, M. I. C. E.

Recent Landslips in Cheshire. By Edward Leader Williams, M. I. C. E.

Dioptric Apparatus in Light-Houses. By Allan Brebner, Jun., Student I. C. E.

Buckie Harbor. By James Barron, A. I. C. E.

Seacombe Ferry Improvement Works. By Wilfrid S. Boult, A. M. I. C. E.; and John James Potts, A. M. I. C. E.

Corn Mill Machinery. By William Baker, Henry Simon and William Bishop Harding.

Coal-Washing. By Thomas Fletcher Harvey, A. M. I. C. E.

REPORT OF NEW YORK STATE SURVEY FOR 1880. By James T. Gardner, Director.

SIGNAL SERVICE NOTES No. 3. HOW TO FORETELL FROST. By Lieutenant James Allen.

MONTHLY WEATHER REVIEW FOR SEPTEMBER. Washington: Government Printing Office.

SCUOLA D'APPLICZIONE PER GL'INGEGNERI, Annual of the Practical Engineering School of the Roman University 1882-3. Rome, Italy.

MANUFACTURE OF RUSSET LEATHER. By Capt. D. A. Lyle, Ordnance Department, Washington.

TEXT-BOOK OF GEOLOGY. By Archibald Geike, LL.D., F.R.S. London: Macmillan & Co.

We can do no better than to indicate briefly the divisions of the subject exhibited by the table of contents.

Book I. Relations of the Earth in the Solar System—Form and Size of the Earth—Movements of the Earth in their Geological Relations.

Book II. A general description of the parts of the Earth—Composition of the Earth's crust including description of the leading simple Minerals and a short treatise on Lithology.

Book III. Dynamical Geology; Hypogene Action; Volcanoes, Earthquakes and causes of Metamorphism. Epigene Action. The Action of Air and Water.

Book IV. Structural Geology, Stratification Joints, Dip, Curvature, Cleavage; The Igneous Rocks and the Crystalline Schists.

Book V. Paleontology.

Book VI. Stratigraphical Geology.

Book VII. Physiographical Geology.

To students of Geology the book is indispensable. It is large for a text book, there being 930 pages of the text. The illustrations 435 in number are fair.

METALLURZISCHEN CHEMIE. Von Carl A. M. Balling. Bonn: Emil Strauss.

The chemistry of the more common metallurgical processes is concisely set forth in this book with little or no attention to mechanical methods.

The Pryo chemical processes are, however, fully discussed, including the properties of the different available fuels.

The application of the principles of Chemical Philosophy to the calculation of quantitative results is also the subject of an important chapter.

DIE MAGNETELEKTRISCHEN UND DYNAMOELEKTRISCHEN MASCHINEN. By Gustav Glaser De Cew. Vienna: A. Hartleben. $1.10.

This is one of a series of technical hand books, and is the first to be devoted to practical electrical science. It gives descriptions of the leading forms of Magneto and Dynamo machines aided by excellent illustrations.

The construction and theory of secondary batteries receive a fair share of attention.

SUBSCALES INCLUDING VERNIERS. By Henry H. Ludlow, U. S. A. New York: D. Van Nostrand. Price 30 cents.

This is a reprint in pamphlet form of an essay bearing this title in the October number of this Magazine.

The theory of all vernier measurements is concisely stated, and all kinds of verniers that are worth imitating are described and illustrated.

DAS GLYCERIN. By Siegfried Walter Koppe. Vienna: A. Hartleben.

The Chemical Constitution, Physical Properties, Manufacture and Uses of Glycerine, are presented in this little German book with fair completeness. Of course Nitro-Glycerine receives a fair share of attention.

The solvent powers of the compound in pre-

paring extracts for chemical purposes are dwelt upon at some length.

The little essay will prove equally useful to pharmacists and to manufacturers of explosives.

CHEMICAL AND PHYSICAL ANALYSIS OF MILK, CONDENSED MILK AND INFANT FOOD. By Dr. Nicholas Gerber; translated by Dr. H. Endemann. New York.

This book, as its title denotes, was originally published on the German language, and was very favorably received.

Professor Dr. C. Declam (Gesundheit V. 267) speaks of it as follows:

One of the most difficult tasks for the chemist is a well executed chemical analysis of milk. A method for the examination of milk, which for hygienic purposes allows to decide easily and exactly the questions concerning its quality, purity or adulteration does not exist, but every contribution thereto must be welcomed. When Dr. Gerber, who for a number of years has been actively engaged in milk industries, undertakes to give us a uniform method of analysis for milk and its products, he merits our sincere thanks. In the work before me the author has omitted to criticize the older methods, as yet in use, in order to not extend the work unnecessarily, some by the accumulation of much scientific material the practical scope of the book might be greatly diminished. He confines himself solely to the description of short though exact methods, which are easy of execution. This communication on the copious, carefully collected and arranged contents will suffice to bear testimony as to the abundance of information to be found in this book. Dr. Gerber's book is to be highly recommended to physicians and sanitarians.

The present English edition has been thoroughly revised and has received such additions as were warranted by the progress of science. Many of the plates which illustrate the German edition have been substituted by better ones taken from the best publications on this subject, while others not contained in the original have been added.

MISCELLANEOUS.

SOME errors in page 437 of the November issue in regard to the Great Lakes are hereby corrected.

Height of Lake Superior above mean high water is 609 feet; of Lakes Huron and Michigan, 589 feet; Lake Erie, 574 feet; Lake Ontario, 247 feet. Lake Huron has, moreover, a width of 105 miles.

CODE OF RULES FOR THE ERECTION OF LIGHTNING CONDUCTORS.—The following rules, from the "Report of Lightning Rod Conference," 1882, published by Messrs. E. & F. N. Spon 16 Charing-Cross, have been abstracted under the directions of Major V. D. Majendie, H. M. Chief Inspector of Explosives, and sent by the Explosive Department of the Home Office to the occupiers of factories, magazines, or stores of explosive materials, and to the police authorities. Reasons, based on practical and theoretical evidence, are given at length in the Report for each rule and recommendation:

1. *Material of Rod.*—Copper, weighing not less than 6 oz. per foot run, the electrical conductivity of which is not less than 90 per cent. of that of pure copper, either in the form of rod, tape, or rope of stout wires; no individual wire being less than No. 12 B.W.G. (.109 in.). Iron may be used but should not weigh less than 2¼ lb. per foot run

2. *Joints.*—Every joint, besides being well cleaned and screwed, scarfed, or riveted, should be thoroughly soldered.

3. *Form of Points.*—The point of the upper terminal of the conductor should not have a sharper angle than 90 deg. A foot below the extreme point a copper ring should be screwed and soldered on to the upper terminal, in which ring should be fitted three or four sharp copper points, each about 6 inches long. It is desirable that these points should be so platinized, gilded, or nickel plated, as to resist oxidation.

4. *Number and height of upper terminals.*—The number of conductors or upper terminals required will depend upon the size of the building, the material of which it is constructed, and the comparative height above ground of the several parts. No general rule can be given for this, except that it may be assumed that the space protected by a conductor is, as a rule, a cone, the radius of whose base is equal to the height of the conductor from the ground.

5. *Curvatures.*—The rod should not be bent abruptly round sharp corners. In no case should the length of a curve be more than half as long again as its chord. A hole should be drilled in string courses or other projecting masonry when possible, to allow the rod to pass freely through it.

6. *Insulators.*—The conductor should not be kept from the building by glass or other insulators, but attached to it by fastenings of the same metal as the conductor itself is composed of.

7. *Fixing.*—Conductors should preferentially be taken down the side of the building which is most exposed to rain. They should be held firmly, but the holdfasts should not be driven in so tightly as to pinch the conductor or prevent contraction and expansion due to changes of temperature.

8. *Other metal work.*—All metallic spouts, gutters, iron doors, and other masses of metal about the building should be electrically connected with the conductor.

9. *Earth connection.*—It is most desirable that, whenever possible, the lower extremity of the conductor should be buried in permanently damp soil. Hence proximity to rainwater pipes and to drains or other water is desirable. It is a very good plan to bifurcate the conductor close below the surface of the ground, and to adopt two of the following methods for securing the escape of the lightning into the earth: (1) A strip of copper tape may be led from the bottom of the rod to a gas or water main—not merely to a leaden pipe—if such exist near enough, and be soldered to it. (2) A tape may be soldered to a sheet of copper 3

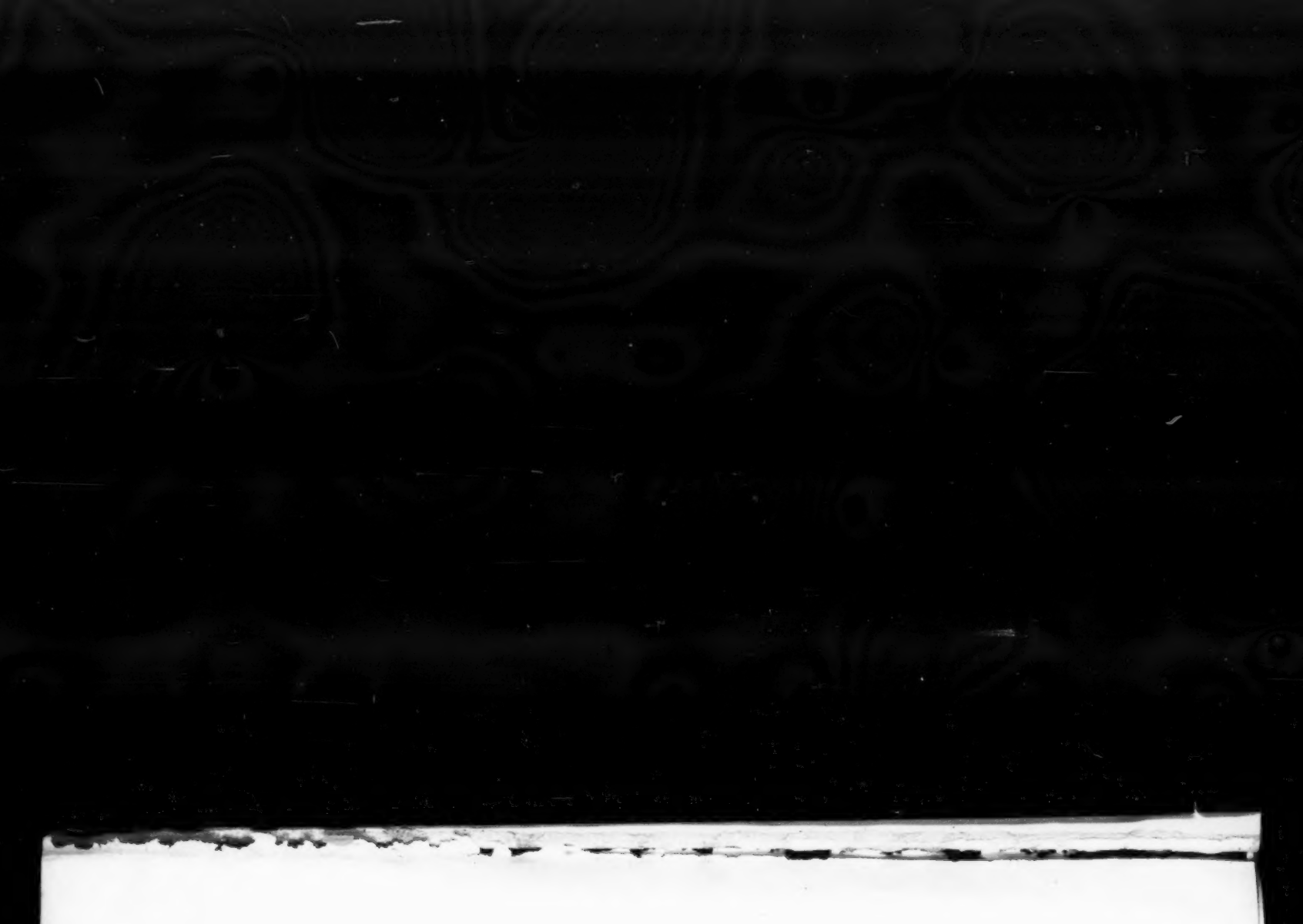
ft. × 3 ft. $\frac{1}{16}$ in. thick, buried in permanently wet earth and surrounded by cinders or coke (3) Many yards of copper tape may be laid in a trench filled with coke, having not less than 18 square feet of copper exposed.

10. *Protection from Theft, &c.*—In cases where there is any likelihood of the copper being stolen or injured, it should be protected by being enclosed in an iron gas pipe reaching 10 ft.—if there is room—above ground and some distance into the ground.

11. *Painting.*—Iron conductors, galvanized or not, should be painted. It is optional with copper ones.

12. *Inspection.*—When the conductor is finally fixed it should. in all cases, be examined and tested by a qualified person, and this should be done in the case of new buildings after all work on them is finished.

Periodical examination and testing, should opportunities offer, are also very desirable, especially when iron-earth connections are employed.

ZINC FOIL IN BOILERS.—Since 1875 experiments have been carried on in the French marine, particularly with boilers having surface condensers; to test the efficacy of zinc leaves in neutralizing the effect of fatty acids in the boiler and giving rise to inoffensive products. Commandant Frené has recently given an account of the results obtained on board the Desaix to the French Academy of Sciences. The zinc inside and the iron of the boiler constitute a voltaic element which decomposes the water and liberates oxygen and hydrogen. The oxygen forms oxide of zinc, which combines with the fatty acids mingled with the feed water, thus forming "soaps" of zinc which, coating the tubes of the boilers, prevent the adhesion of the salts left by evaporation. It is easy then to brush away the fixed matter on the tubes which is in a mealy state. As to the hydrogen, it behaves as MM. Gernez and Donny have described in the *Annales de Chimie et de Physique* for 1875. Ebullition takes place by evaporation at the surface of a gas whether dissolved in the liquid or clinging to the solid envelope of the containing vessel. If the gas is expelled from boiling water the latter can be superheated to 30 deg. or 40 deg. Cent. above the normal boiling point, and in such a case evaporation only takes place at the surface. When the temperature of the vapor emitted corresponds to the tension which equilibrates the pressure exercised at the surface of the liquid, the ebullition can be started at will by introducing a gas bubble into the liquid. Solid bodies operate in the same way by reason of the film of gas adhering to them. When by long boiling all the gas is expelled, the water becomes superheated, and thus an element of danger is introduced. But by the employment of zinc in the boiler a constant supply of gas is maintained, and all danger of superheating is avoided. The hydrogen not only starts the boiling, but keeps it up. It is, however, necessary from time to time to take out the zinc plates from the boiler and clean from them the salts adhering to them, else the galvanic action will dwindle and perhaps stop altogether. M. Frené is of opinion that the action of the zinc is, however, not so regular as theory might expect, and advocates the substitution of a sure and constant mechanical action under the form of a moderate but continuous injection of warm air by the lower part of the boiler, or better still, a non-oxidizing gas, such as carbonic acid. This plan he thinks would produce a perfectly regular ebullition, a rapid evaporation, a saving of fuel, and freedom from risk. Superheating, which he figuratively calls a sleep of the liquid, would be no longer possible. The carbonic acid could be developed by the combination of carbonate of lime and hydrochloric acid.

M. DE VILLIERS has invented a metallic alloy for silvering. It consists of 80 parts of tin, 18 parts of lead, and 2 parts of silver, or 90 parts of tin, 9 parts of lead, and 1 part of silver. The tin is melted first, and when the bath is of a brilliant white the lead is added in grains, and the mixture stirred with a stick of pine wood, the partially melted silver is added, and the mixture stirred again. The fire is then increased for a little while, until the surface of the bath assumes a light yellow color, when it is thoroughly stirred up and the alloy cast in bars. The operation is then carried out in the following manner: The article, a knife-blade for example, is dipped in a solution of hydrochloric or sulphuric acid, rinsed with clean water, dried and rubbed with a piece of soft leather or dry sponge, and finally exposed to a temperature of 70 deg. or 80 deg. Cent.—158 deg. to 176 deg. Fah.—for five minutes in a muffle, to prepare the iron or steel to receive the alloy, by making the surface porous. If the fron is not very good these holes are much larger, and frequently flaws and bad places are disclosed, which make the silvering more difficult. With steel the process goes on very regularly. The article, warmed to, say, 140 deg. Fah., is dipped in the bath, melted in a crucible over a gentle fire. The bath must be perfectly fluid, and is stirred with a stick of pine or poplar; the surface of the bath must have a fine white silver color. For a knife-blade an immersion of one or two minutes is sufficient to cover it; larger articles require five minutes immersion. After taking it out of the bath it is dipped in cold water, or treated so as to temper it if necessary. If left too long in cold water it frequently becomes brittle. It is then only necessary to rub it off dry and polish without heating it. Articles treated in this manner look like silver, and ring like it too, and withstand the oxidizing action of the air. To protect them from the effect of acid liquids like vinegar, they are dipped in a bath of amalgam, composed of 60 parts mercury, 39 parts of tin, and 1 part of silver; then dipped warm into melted silver, or electro-plated with silver to give them the silvery look. This kind of silvering is said to be very durable, and the cost comparatively small. If this method is as good as the inventor represents it, the *Scientific American* thinks it will be preferred to nickel-plating.